Video Camera Technologies Systematization

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Yasuo Takemura

■ Abstract
The video camera is a color television camera for consumer use that makes it possible for anyone to take, record and save a moving picture. This paper surveys developments in consumer video camera technology.
Video cameras have been developed and manufactured in Japan for several decades and exported to global markets. Many kinds of video camera technologies developed in Japan have been applied to digital still cameras, mobile phones for communication, and even smartphones and tablets.
Although compact in size, the video camera system includes a myriad of basic technologies covering a wide range of technical fields, including optical systems and lenses, image sensors – the key device in photoelectric conversion, digital signal processing for reproducing high-quality, highly-functional images, recording systems for recording images and high density mounting to bring it all together in a compact form. Furthermore, the video camera must also be small, lightweight, durable and energy-efficient, as well as the basic consumer requirements of low pricing and high reliability.
The image sensor industry has developed into one of Japan’s most successful industries, supported by the timely and rapid advancement of semiconductor technology and accompanied by a wealth of specialized research. Japanese consumers expect high fidelity image quality, which has driven the development of high-quality television and video camera technologies through collaboration between sensor technology engineers and camera technology engineers, resulting in world-class quality video camera technology.
Many successful image sensor technologies have been developed by Japanese engineers, such as pinned photodiodes that significantly reduce noise levels, FIT-CCD image sensors that resolve the problem of image smear, on-chip micro-lenses that enable significantly better light utilization efficiency, VOD technology to rectify issues of image blooming, interlaced addition readout, residual charge sweep-out drive technology, color-difference line-sequential systems for increasing photographic sensitivity suitable for interlaced scanning to deliver enhanced resolution. These have all been combined to produce world-class video cameras.
Japan has brought out a succession of world firsts in video camera products. The world’s first single-tube video camera for consumer use, the IK-12, was commercialized in 1974 by Toshiba. This was followed by the development and commercialization of various tube-type video cameras. In 1980, Hitachi hit the markets with the world’s first solid-state, single-chip MOS image sensor video camera, the VK-C1000. In 1982, the world’s first CCD video camera, the TC-100, was commercialized by NEC, with heated competition ensuing over development and commercialization. In 1983, Sony released the BMC-100, a video camera with an integrated Betamax VCRfor recording. Later, in 1985, two types of small-scaleVCR systems were developed for integrating with video cameras, the VHS-C and 8mm. The Japan Victor Company (JVC) commercialized a VHS-C video camera, while Sony did the same with an 8mm video camera, the CCD-V8. Sony’s passport-sized compact video camera, the CCD-TR55, hit the markets in 1989 and the video camera industry truly began to take hold of the market. The competition over increasing pixel numbers was brought to a close by Toshiba unveiling its AI-XS1 high-resolution 420,000-pixel video camera. Highly functional and increasingly user-friendly video cameras then began hitting the market.
Developments in video camera technology came to be widely used in surveillance, industry, medicine and other fields, producing ripple effects whereby Japanese manufacturers began unveiling a slew of world-first products, such as the color TV telephone in 1970, the electronic endoscope in 1983 (while the United States produced the world-first, Japan currently produces 70% of all electronic endoscopes), a thumb-sized camera in 1981 and a stereoscopic video camera in 1989.
The reason that Japanese video camera technologies came to dominate world markets is largely due to cooperation among Japanese engineers, who exhibited a strong desire to develop new technologies in the midst of a fiercely competitive environment. In the early stages of CCD development, the technology fell short compared to the then mainstream high-end camera tubes, a situation that vexed engineers specializing in the technology, not to mention the companies they worked for. They dreamed of future success. A strong sense that they shared a common objective led engineers from competing companies to raise concerns at academic conferences, which in turn prompted sound advice from willing mentors. Image sensor and camera engineers joined forces to propose and resolve issues, gathering together the best people and nurturing talented engineers. Eventually, patent filings and successive presentations of technological achievements at gatherings of professional associations such as the IEEE and worldwide academic conferences resulted in Japan gaining global recognition for its unparalleled technological excellence.
Research and development in this field appears to have turned a new corner in the 2000s. The advancement of digital technology and software ushered in a new direction. Scientific associations turned their attention to new technology, such as super-resolution technology using a mathematical approach to improve the resolution of captured images and computer imaging technology to reproduce images by capturing and converting light fields. In response to environmental changes, Japanese engineers are again laying the groundwork for new technologies to blossom. Japanese engineers excel at using new methods to create high-quality images.
From here on in, there are high expectations regarding the boundless possibilities for advances in camera technology. The world is watching for new technological innovations from Japan that will bring new camera products to fruition.

Contents

■ Profile

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March 1962 Graduated from Waseda University First School of Science and Engineering, Electrical and Communications Engineering Department

April 1962 Employed by Tokyo Shibaura Denki Co., Ltd. (now Toshiba Corporation)
Posted to the Central Research Laboratory
Involved in research and development of imaging technologies, including a color television pickup system and video cameras

September 1994 Retired from Toshiba
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March 2002 Established Oct Imaging Lab. Co., Ltd.
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IEEE Fellow and ITE Honarary Member (ITE: The Institute of Image Information and Television Engineers of Japan)

1. Preface

Video camera technology is one of the few products to have originated in Japan and been perfected by Japanese engineers, bringing together a wide range of technologies. Consumer video devices include television receivers, VCRs, cameras and DVDs. All of these were developed by Japanese engineers and have gone into mass production. Of these, the camera has undergone the most changes, from television cameras for broadcasting, to video cameras for home use, dedicated still-image digital cameras, mobile phones for communication and multifunctional smart phones. In each case, Japanese technology has led the world. Video cameras have played a central role in this progress, providing a foundation of research and development to be passed on to future cameras.
While the key device in the camera, the CCD, was invented in the United States, it depended on Japanese semiconductor technology. With the incorporation of unique CCD processing technology, it rapidly improved in performance and developed into a device capable of being mass produced. Camera engineers were fastidious in their devotion to image quality and many new imaging technologies were produced, raising the degree of perfection of the video camera.
Even in the early stages of video camera development, high performance broadcasting cameras were being put to practical use. However, these cameras had to be operated by experienced, professional camerapersons and required over 30 minutes of careful maintenance and adjustment before broadcasting began to obtain a high-quality image. These were far unacceptable from consumer cameras that anyone could use.
In order to be able to bring these broadcasting cameras into the home, they had to be smaller in size, lighter in weight, more robust and require no adjusting. This first of all required an improvement in basic camera performance. The most pressing task to achieve this was to develop a useable image sensor. Following that, to make the camera smaller and more lightweight, it was necessary to develop a single-chip image sensor to combine the three-chip CCD into one and dispense with the color-separation prism. With the image size reduced, it was necessary to make the imaging lens smaller and more lightweight. Further, the camera adopted LSI chips, improving the circuitry and eliminating the areas for adjustment, thereby reducing the number of components. To make it compact, it was also necessary to incorporate high-density mounting technology. Meanwhile, to make the camera easier to operate, it was necessary to automate the exposure, focus and color temperature adjustments. Collaboration with optical manufacturers in Japan resulted in Auto Iris (AI), Auto Focus (AF) and Auto White Balance (AWB). Image stabilization was also necessary for handheld shooting.
This report outlines the details on the development of these technologies based on documented materials and clarifies how Japanese technological development was able to lead the world.
Chapter 1 includes the preface and outlines the development of the video camera. Chapter 2 discusses optical systems for effective image formation of a subject; Chapter 3 covers image sensors, the key device in these cameras; Chapter 4 discusses single-tube color imaging systems; Chapter 5 covers CCD color imaging systems; Chapter 6 discusses the video camera, the key subject of this report; Chapter 7 covers recording devices for cameras; Chapter 8 discusses the high performance processing required for capturing good images; Chapter 9 covers digital signal processing required for high image quality; and Chapter 10 provides a systematization of the above.
In keeping with the aim of this report, technical descriptions have largely been left out. Readers seeking the technical details are invited to refer to the following works.

Reference Works

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1.1 Imaging Technology

The origins of imaging technology can be traced to a mechanical imaging device made by Paul Nipkow in 1884. This is based on a German patent applied for in January 1884 and registered the following year in January 1885 [1]. Part of this memorable patent is shown in Fig. 1.1. The detailed description demonstrates the concept of a disc-type imaging device, as shown in Fig. 1.2. However, it was a long time until anyone put this idea into practical use.

Kaiserliches Patentamt

KAISERLICHES PATENTAMT.

AUSGEGEBEN DEN 15. JANUAR 1885.

PATENTSCHRIFT

— № 30105 —

KLASSE 21: ELEKTRISCHE APPARATE.

PAUL NIPKOW IN BERLIN.

Elektrisches Teleskop.

Patentirt im Deutschen Reiche vom 6. Januar 1884 ab.

Der hier zu beschreibende Apparat hat den Zweck, ein am Orte *A* befindliches Object an einem beliebigen anderen Orte *B* sichtbar zu

durchlaufenden polarisirten Lichtstrahles unter dem Einflufs eines die Spirale durchstreichenden elektrischen Stromes zu drehen, z. B. ein Cy-

Fig. 1.1. Part of the Nipkow Patent

In 1926, John Logie Baird [2] of the United Kingdom carried out the world's first successful television experiment using the Nipkow disk. The memorable day was January 26, 1926 [3]. Remote television transmission over 438 miles between London and Glasgow was successfully accomplished in 1927. In addition, intercontinental transmission was also successfully achieved between London and New York in 1928.
Meanwhile, Vladimir Kosma Zworykin [4] invented a fully-electronic television system in 1923 and an iconoscope camera tube that enabled the electronic camera in 1930.
Mechanical television systems had a fundamental problem in that they were incapable of producing a high quality image. These systems ran into difficulty with the emergence of electronic systems combining camera tubes and cathode-ray tubes.
BBC evaluated the fully-electronic, 405 scanning-line Marconi system and the mechanical, 240 scaning-line Baird system and in 1935, decided to adopt the fully-electronic system [5].
In contrast to these overseas developments, Kenjiro Takayanagi of Hamamatsu Higher Industry and Masataro Kawarada and Tadaoki Yamamoto of Waseda University were respectively carrying out their own independent research and development.
In March 1930, both systems were demonstrated for the first time at the memorial exhibition of the fifth anniversary of radio broadcasting, held in the municipal hall in Hibiya, Tokyo [6].
The NHK (Japan Broadcasting Corporation) put all its efforts into development, with the aim of providing television broadcasting of the Tokyo Olympics, scheduled to be held in 1940. Takayanagi participated as a development director, and experimental television broadcasts were begun in 1939. However, the Tokyo Olympics were canceled due to the deterioration of the international situation, and all television developments were interrupted with the outbreak of World War II.
Table 1.1 shows a brief history of television, including later developments.
The Television Society was established soon after the war and television development began. Japan initially fell far behind the United States due to the impact of the war.

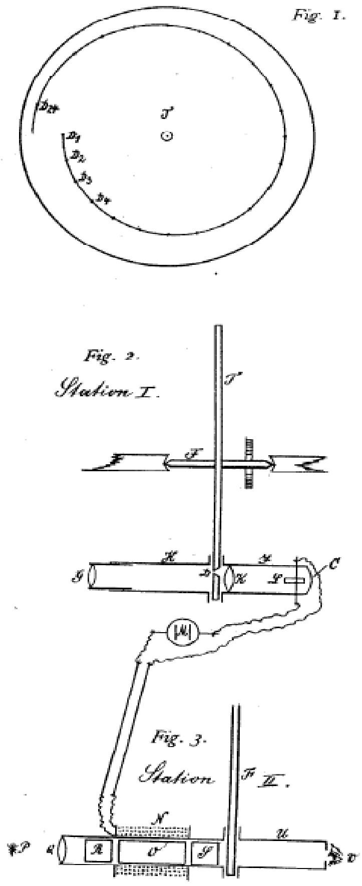


Fig. 1.2. The Nipkow Disc

Table 1.1 Television-Related History, created with reference to sources (1)-(8)

Year	Name of person/organization	Event	Comments
1884	Nipkow	Invention of the Nipkow disc	
1897	Braun	Invention of CRT tube	
1923	Zworykin	Invention of full-electronic television	
1925	Baird	Invention of the world's first mechanical scanning television	
1926	Kenjiro Takayanagi	Successful reproduction of the character "イ"	
1930	Yamamoto, Kawarada, Takayanagi	Demonstration of the Waseda-type and Hamamatsu-type televisions	
	Zworykin	Invention of Iconoscope pickup tube principle	
1933	Zworykin	Iconoscope announced	
1935	Tokyo Electric Company	Japan's first Iconoscope developed	
1936	BBC	Television broadcasting commenced; 441 scanning lines, 25 fps interlaced	
1937	NHK under the direction of Takayanagi	Television Development started for the Tokyo Olympics	
1939	NHK	Experimental television broadcast started	
1941		Experimental TV broadcasting discontinued, research and development also discontinued	
1946		Television Association established	
1950		The Institute of Television Engineers in Japan established	
1953	NHK	Television broadcasting started *	February 1
	Nippon Television Network Corporation	Commercial television station started broadcasting	August 28
1960		Color television broadcasting started	September 10
1963		Successful satellite relay experiment between Japan and the USA **	November 23
1969		Satellite rely of the first man stepping on the moon from Apollo 11	July 21
1989		Satellite broadcasting started	June 1
		HDTV (analog) practical test broadcasting started	
2000		BS digital broadcasting started	December 1
2003		Digital terrestrial broadcasting started	December 1
2011		Analog TV broadcasting ended ***	July 24

* 4 hours/day, 886 reception contracts
** Breaking news on the assassination of President Kennedy
*** Except for Iwate, Miyagi and Fukushima due to earthquake impact

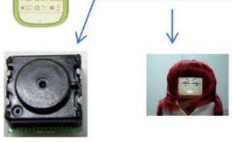
1.2 Video Camera Technologies

In the early days of television in the 1940s and 1950s, a television camera was black and white. At the time, camera image can take somehow, half-tone image reproduction was poor. At the 1964 Tokyo Olympics, a domestically-produced two-tube color camera succeeded vividly in reproducing the image of the opening ceremony. The image of the smoke from the torch held by athlete Sakai among the crowds in the newly-completed National Stadium was being relayed across the entire country at the same at the same time across the country. Even now, this beautiful color image is still burned into our eyes. In 1970, the World Exposition was held in Osaka and dances and national costumes from around the world were aired on color TV every night. Through national events of these, the quality of the color camera improved greatly, and color television receivers grew rapidly in popularity. Home use VCR (Video Cassette Recorder) gradually began to increase in popularity with the rapidly growing demand to record programs. Broadcasting cameras were equipment operated by professional technicians. These cameras could only achieve color images with careful adjustment before broadcasting start. Accordingly, research and development on video cameras fell far behind that of television receivers, which were intended for consumer use from the outset.

As home use VCRs began to grow in popularity, there was an increasing demand from people wanting to record their own images. Video cameras attracted the attention of Japanese manufacturers, who started competing on research and development in this area. While this has turned into a major industry, changing in format from digital cameras to mobile phones, smartphones and tablets, much of the basic technology was developed for these video cameras.
Unlike the conventional broadcasting cameras, video cameras were operated by amateurs. They had to be able to reliably capture images by anyone, anywhere. Furthermore, they had to be small, lightweight, uniform in quality, able to be mass produced and able to be sold at affordable prices.
Japanese engineers struggled and worked hard to produce a large number of world number one class technologies. In the following, we would like to clarify the facts together with evidence on the basis of technological development.

With the popularization of video cameras, digital cameras, mobile phone cameras and other consumer use camera appliances, cameras have undergone various changes, each with their own unique technological developments. In other industries, a product is completed, gains popularity and eventually goes into decline. By contrast, camera technology has progressed by successively creating new products in different forms.

TV Cameras	Broadcasting Stations	1960s-1970s
Video Cameras	Home use	1980s-2000s
Digital Cameras	Photography	Late1990s-
Cellular Phones	Communication	Late 2000s-
Smart Phones	Computers	Early 2010s-
Vehicle Cameras	Safety and Security	Late 2010s-
Intelligent Toys	Nursing and Multipurpose	2020s-



Any Japanese technology →
Exported to the world

Fig. 1.3. Progress in Major Epoch-Leading Camera Technology

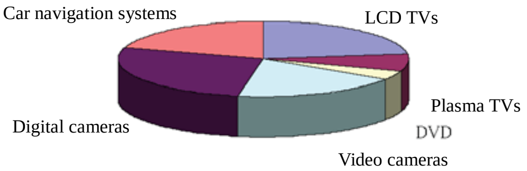
Major cameras and the camera technologies used for these are shown in Fig. 1.3. We can appreciate how the intended images have slightly altered each time and how the research and development has progressed. A wide range of applications for cameras can be expected in future, such as vehicle-mounted cameras for passenger vehicles and intelligent cameras for education, nursing care and the like.

Imaging technology has also been extensively utilized many other fields, including surveillance cameras for security, endoscopes for medical treatment, industrial cameras for assembly lines and high-speed cameras for scientific research.

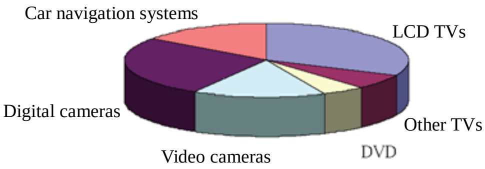
A distinguishing characteristic of the video camera is its contribution to Japanese industry. As a result of early price competitions with TVs and VCRs, many companies set up bases overseas and developed their overseas production, thereby losing opportunities to boost the domestic industry and create employment. By contrast, video cameras have long played a central role in the video equipment industry by combining multiple superior technologies and by domestic manufacturers having the monopoly on production of the key device, the CCD.

Fig. 1.4 shows domestic production of video equipment on a monetary basis. Together, video cameras and digital cameras account for almost half of production in 2004-2005 on a monetary basis. These figures are shown in Table 1.2.

However, two years later, in 2008, a decline began to show among cameras.



(a) 2004

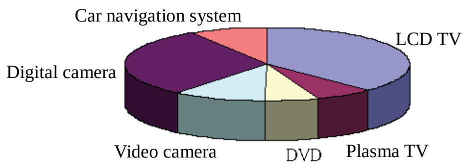


(b) 2005

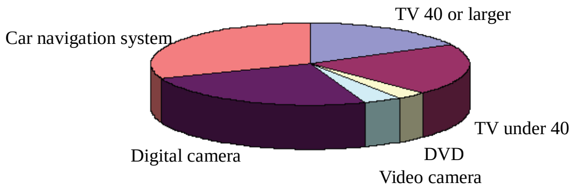
Fig. 1.4. Domestic Production of Video Equipment 1 (Monetary-Based Comparison) [9]
– cameras account for almost half

Table 1.2 Domestic Production of Video Equipment (unit: billion ¥) [9]

Item	2004	2005	2008	Item	2011
Liquid crystal TVs	550	874	875	TVs	
Plasma TVs	173	-	158	40 inch or larger	258
Other TVs	-	182		Under 40-inch	300
DVD	94	138	142	DVDs	46
Video cameras	439	418	246	Video cameras	58
Digital cameras	650	736	706	Digital cameras	370
Car navigation systems	476	416	211	Car navigation systems	461



(a) 2008



(b) 2011

Fig. 1.5 Domestic Production of Video Equipment 2 (Monetary-Based Comparison) (9)
– decline showing among cameras

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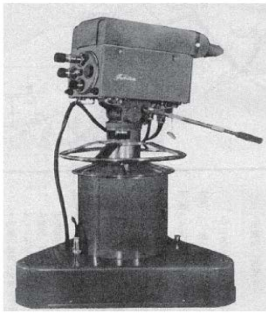
(9) Taken from a video production equipment performance table in the Ministry of Economy, Trade and Industry production dynamics statistics.

2. Optical Apparatuses

Video camera optical apparatuses include a wide range of technologies, such as imaging lenses, optical LPFs (Low Pass Filters), dichroic prisms and CFAs (Color Filter Arrays).
Due to space limitations, let us provide history of only the major technological developments.
Japanese excellent optical technology is said to be based on technology developed for naval submarine periscopes. Japan Optical Co., Ltd. (now Nikon) started producing weapons for the navy around 1930. In 1932, the army founded Tokyo Optical Company (now Topcon) to start its own production (1) which was invested by Hattori Seikosha, with the acquisition of Katsuma optical Machinery Co. Both companies worked on technological developments, and it was said Japan Optical for the navy and Tokyo Optical for the army. The Tokyo Optical Company produced equipment such as range finders and sighting devices. In 1934, Canon was founded as Precision Optical Industry Co., Ltd., producing Japan's first prototype focal plane shutter camera the same year. Nikon was established in 1917 as Japan Optical Co., Ltd. through a merger between the optics department of Tokyo Instrument Works and the reflector department of Iwaki Glass Works, funded by Koyata Iwasaki, president of Mitsubishi Joint Stock Company (2).
Major camera optical system technologies are shown in Table 2.1.

2.1 Imaging Lens

The imaging lens is the most important optical component affecting camera image quality. In the 1950s, television cameras had three or four lenses of different focal lengths, as shown in Fig. 2.1 (a). This was called the turret type; these lenses were altered in accordance with the desired scene. Television cameras designed for shooting moving images required a zoom lens; accordingly a zoom lens was developed (3)-(10). As shown in Fig. 2.1(b), a camera with the zoom lens in the standard was appeared.



(a) Turret lens attached

(b) Zoom lens attached

Fig. 2.1 Broadcast Camera and Lenses

Table 2.1 Chronology of Camera Optical Technology, created with reference to literature (44)

Year	Manufacturer	Item
1958	Canon	The first domestically-produced television camera zoom lens
1959	Canon	The first domestically-produced studio zoom lens, 45-200mm / F2.8
1964	Philips	3P (Plumbicon) camera using dichroic prism (13)
1965	Fuji Photo Optical	High performance 10x zoom lens for 3 inch IO camera, 80-800mm/F2.0 Widely used in baseball game broadcasts
1967	Toshiba	Black level stabilization (41)
1968	Canon	1.25 inch PbO studio zoom camera lens (P10x20)
1969	NASA	Live color television relay from the Apollo 11 spacecraft to the whole world (frame sequential)
1970	Fuji Photo Optical	10x / F1.6 zoom lens (R10x16) for TK-301 Fitted on all NHK colorization standard camera
1970	Canon	Three-color separation prism built in bias light (14) Lag reduction of specific plumbicon
1971	Nippon Columbia	Crystal filter using birefringence (30)
1972		Diffraction grating phase filter (RL Townsend) (31)
1976	Fuji Photo Optical	10x / F2.0 zoom lens (A10x10.5) for ENG 2/3 inch camera Compact and lightweight
1976	Kodak	Bayer CFA invention
1980		The first autofocus lens (P18x16 B-AF) mounted in TV-camera Active AF-TTL system (TTL: Through the Lens)
1982	Canon	1 inch HDTV camera zoom lens (PV40x13.5) Widely used in the 1984 Olympics held in Los Angeles
1983	NEC	On-chip micro-lens (32)
1984	Canon	1 inch HDTV camera zoom lens (PV14x12.5HD)
1986	Toshiba	16.5mm diameter ultra-compact camera lens
1989	Toshiba	Compound eye lens for stereoscopic cameras
1993	Canon	First optical image stabilizer broadcasting lens fitted with a variable angle prism J14ax17KRS-V
1993	Fuji Photo Optical	Aspherical 10.5-378mm, F2.0, 36x zoom lens A36x10.5 for ENG

I 1958, Japan's first zoom lens has been developed by Canon [2]. Broadcasting cameras were mainly three-tube, three-chip cameras with dichroic prisms. It is necessary to increase the back focus in order to mount the prism, so there were design limitations. Then, single-tube or single CCD camera is mainly used for home use, eliminating this design constraint.
Conversely, the RGB three images had to be focused on the same plane, design to minimize chromatic aberration is required. In the HDTV age, higher resolution was required [11] [12].
Since video camera had to be able to be easily used by anyone, auto light control system was adopted at first, after that, auto focus and auto white balance spread further, and image stabilization also began to be adopted. Competition became increasingly to make the camera smaller and more lightweight. The lens size was also decreased by the adoption of plastic lenses and aspherical lenses.

2.2 Dichroic Prism

The dichroic prism is an optical component by which the light incident on the lens is focused and separated into a three-color RGB optical image. The dichroic prism was proposed by Philips in 1960 [13] and became an essential optical component in the three-tube, three-chip CCD camera. As shown in Fig.2.2, it is formed from three prisms. Since the blue light rays are reflected selectively at the first surface and next, the red light rays are reflected at the second surface, only green light rays are transmitted. Since the reflected red and blue light rays respectively form images in the two reflections, they become inverted images, the same as the G image.

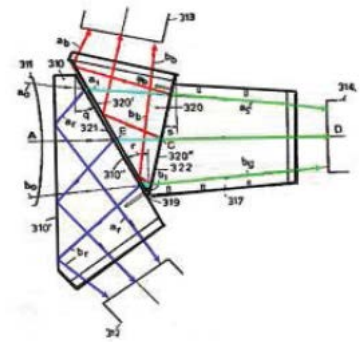


Fig. 2.2 Dichroic Prism [13]

It was later discovered that a bias light is effective in reducing lag in Plumbicon camera tubes, and new built-in bias light dichroic prism was developed [14].
Technology was developed to directly fix CCDs to the dichroic prism with high accuracy in a three-chip CCD camera [15]-[17]. This eliminated the problem of RGB image color shift during operation, because unlike in a camera tube, the photosensitive surface of a CCD is determined accurately in a pixel array and does not fluctuate.

Three-chip CCD technology even started being used in high-end video cameras. Automated fix technology was developed to accurately secure the CCDs, making full-scale mass production possible.

2.3 CFA (Color Filter Array)

The Bayer type CFA [18] was proposed by Kodak in 1976 and RGB primary color type became a mainstream. Initially, CFA for single tube color camera was used a stripe filter. A multi-layer interference coating was used, as the camera tube required high heat processing. Toshiba developed the technology to reverse-etch the stripe pattern on around 30 layers of coating at a width of around ten microns. These were mass produced by Fuji Photo Optical. This allowed the commercialization of the Chromicon color camera tube [19], which paved the way to the world's first single-tube video camera [20].
Competition began in 1980 over CFA development, along with CCD development. A method was adopted to bond the CFA over the CCD with high precision. To reduce production costs, the inorganic interference-coated filters were replaced with organic dye filters. It was discovered that CFAs could be produced using printing technology and printing companies such as Toppan Printing and Dai Nippon Printing became involved in video camera production.
However, it became increasingly complicated to separately produce CCDs and CFAs and bond them together and waste management became increasingly difficult. Accordingly, progress was made on technological developments to form the CFA directly on the surface of the CCD [21]-[26].

2.4 Optical LPF (Low Pass Filter)

Obtaining a color signal from a CCD using a CFA requires sampling. This can generate a false signal if the subject has a high-frequency component that is half or more of the sampling frequency that overlaps with the aliasing component, as shown in Fig. 2.3.

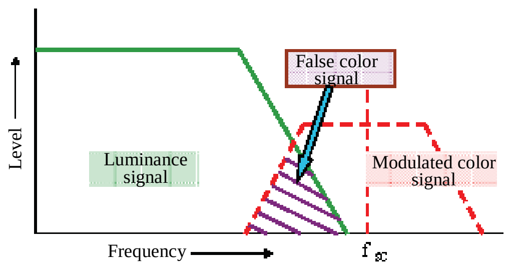
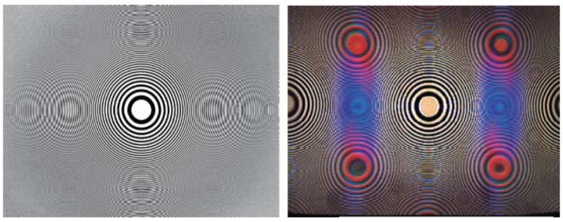


Fig. 2.3 Cause of False Color Signal Generation

Table 2.2 Types of Optical LPF

Type	Composition	Characteristics
Crystal	Uses artificial crystal double refraction Used in most CCD cameras	Any characteristics possible, depending on the thickness Relatively sharp cut-off characteristics
Lenticular	Parallel arrangement of cylindrical lenses	Any characteristic can be achieved through pitch and curvature selection Adjusted by lens pupil position
Phase Grating	Phase difference provided by irregularities in a stripe or grid pattern	Different cut-off characteristics for different colors Provided to lens pupil position
Christiansen Filter	Scattering material with different characteristics at specific wavelengths distributed in a liquid	Different cut-off characteristics available for different colors Difficult to achieve directionality



(a) CZP chart (b) False signal generation

Fig. 2.4 Cause of False Color Signal Generation

Fig. 2.4 (a) is a CZP (Circular Zone Plate) chart in which the spacing and width of the ring gradually narrows towards the outside from the center. As shown in Fig. 2.4(b), when this chart is taken by camera, countless rings appear where there were no rings originally. These are all false signals. To eliminate the false signals, the high-frequency component of the subject should be removed. To achieve this, an optical low pass filter (LPF) is used [27] [28]. There are many kinds of these, as shown in table 2.2 [28]. Most filters currently in common use are artificial crystal filters that use the birefringence of the crystals [29] [30], while some are phase diffraction grating filters [31].

2.5 Micro-Lens

Only the light incident on the photodiode part of the surface of the CCD contributes to photoelectric conversion; light incident on any other area is of no effect. Therefore, if the surface is not treated with anything, the light utilization drops to 20-30%.
To solve this problem, a method has been adopted to improve the utilization of light by providing a micro-lens on the top of the photodiode. Like the CFA, this is also integrated onto the surface of the CCD.
This was first announced by the NEC in 1983 [32]. Later mass production of this process has contributed to improve sensitivity [33] [34].
With the recent miniaturization of pixels, the photodiode has had to become more deeply positioned into the surface, light has not reached effectively.
To solve this problem, various improvements have been applied, such providing a layer lens on the surface [35]-[40].

2.6 Other Optical Components

Let us now discuss color reproduction and methods used to obtain reference black levels.

2.6.1 OB (Optical Black)

Black level stabilization is important in the video signal. Without a stable reference black level, a video signal will lose its color balance and the dark and light levels in the image will be unstable. This stabilization is achieved by setting a reference voltage and clamping the video signal to this level.
OB is necessary for providing the reference potential. OB had been proposed by Toshiba in the camera tube era, as shown in Fig. 2.5 [41]. This is a principal technology currently used in all CCD and CMOS image sensors.

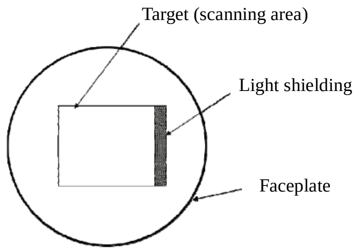


Fig. 2.5 Optical Black [41]

2.6.2 Color Fidelity

Color fidelity is an important technology for the video camera and research and development has been carried out for broadcasting cameras [42] [43].
After having added a correction to the results calculated based on the color characteristics of the three primary colors of the display device, the spectral characteristics of the primary color filter is used as shown in Fig 2.6.
Meanwhile, the color temperature of the light source and wavelength spectral characteristics are important, the camera is designed to take automatic white balance according to the color temperature of the light source.

Due to space constraints, please refer to the cited reference materials for more detail.

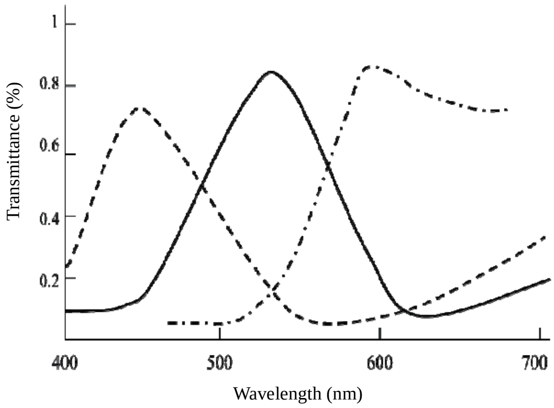


Fig. 2.6 Example Spectral Characteristics of an RGB Filter

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3. Imaging Devices

3.1 History of Imaging Devices [1]

Let us outline the development of imaging devices, the key elements in the video camera.

3.1.1 Image Pickup Tube

Imaging device that was used for the first home use video camera was a Vidicon, which is a type of image pickup tube. These image pickup tubes were used for the first decade. In 1970, Bell Laboratories announced the CCD (charge-coupled device), and manufacturers around the world started on research and development on this new technology. This research and development kept pace with advances in Japanese semiconductor technology and by the late 1980s image pickup tubes were being replaced by CCDs.

The history of imaging devices can be summarized as shown in Table 3.1. The first imaging device used for television camera is said to be Nipkow mechanical disk of 1884. The image dissector was the first electronic device in about 50 years later, although it had very poor sensitivity due to having no charge storage capabilities. Iconoscope was the first storage-type image pickup tube. Image orthicon improved the performance of the Iconoscope, and was widely used in the age of black and white television broadcasting. Image pickup tubes were used in the early stages of color television broadcasting. However, while the IO had some outstanding characteristics, it required careful adjusting of the electron beam and other elements prior to use and was not suitable for general use.

Next, a photoconductive type image pickup tube appeared using a photoelectric effect to alter the electrical resistance according to the amount of light . The Vidicon, devised by Weimer et al of RCA using Sb_2S_3 as a photoconductive film, was used extensively in industrial and home use cameras.

The world's first single-tube color camera for home use had a Vidicon tube with a built-in color filter. It was released by Toshiba in 1974 at a price of ¥298,000. This camera is regarded as the first color cameras for home use in earnest[2].

The Vidicon tube had the disadvantage of being susceptible to lag. This was solved with the Plumbicon tube, which used a PbO photoconductive film. These tubes were used in most three-tube color cameras for broadcasting.

3.1.2 Solid-State Image Sensor

In contrast to image pickup tubes, imaging devices that use semiconductor technology are called solid-state image sensors [3]. Practical research and development on solid-state imaging devices began after the invention of the CCD [4] [5]. These were initially also called charge-transfer devices (CTDs) and included the BBD [6] and CID [7] [8].

Table 3.1 Progress in Image Sensors

Type	Name
Mechanical	Nipkow disc (1884)
Electronic	Image Dissector (1931 Farnsworth)
	Iconoscope (1933 Zworykin)
Image type	Image orthicon (1946 Zworykin)
	SEC (1964 Westinghouse)
	SIT (1971 RCA)
Photoconductive type	Vidicon (1940 RCA)
	Plumbicon (1962 Philips)
	Chalnicon (1971 Toshiba)
	Saticon (1972 NHK and Hitachi)
	Newbicon (1974 Panasonic)
Photomultiplier type	HARP tube (1994 NHK)
Solid state	
XY address	Photoscanner (1963 Honeywell)
	TFT (1964 RCA)
	Scanistor (1964 IBM)
	Phototransistor Array (1966 Westinghouse)
	MOS type image sensor mass production (1981 Hitachi)
Charge transfer	BBD (1969 Philips)
	CCD (1970 Bell System Lab.)
	CID (1971 Philips)
	CPD (1979 Panasonic)
	Accordion CCD (1984 Philips)
	CSD (1984 Mitsubishi Electric)
CMOS	CMOS image sensor (1993 Fossum)

3.1.3 CCD

The emergence of the CCD accelerated the research and development of solid-state imaging devices [9]. Major semiconductor manufacturers, such as Toshiba, NEC, Hitachi, Matsushita Electronics and Sony have participated in research and development all at once in Japan. In the 1980s, a large number of engineers had gathered in the study group of the image sensor, held by the Institute of Television Engineers organized. After the meetings, engineers from all manufacturers alike would enthusiastically discuss their ideas together late into the night, honing their technological strengths and combining forces to commercialize products [10] [11]. This energy paved the way to bring Japanese imaging technology to the top of the world today [12] [13].

The biggest obstacle to commercializing the CCD was a constant battle with dust and scratches during the manufacturing process. CCDs have a large photosensitive surface and all 200,000 pixels in the sensor must be free of defects for it to operate. Even if the press release of commercialization was performed, each manufacturer took considerable time before an actual product emerged. [14] [15].

3.1.4 CMOS Image Sensor

While the CCD had been regarded as the definitive imaging device for video cameras, the movement of a new imaging device came out of the late 90's from expectations of small size of the camera and high integration of LSI. In order to obtain a high performance characteristics, CCD required three power sources, high-voltage power supply of 10V and about ±3-5V. This was difficult to achieve with a single chip that also included the circuitry.

Under these circumstances, E. R. Fossum proposed an active-type CMOS image sensor in 1993. This is regarded to be the first of today’s CMOS image sensors [16]. CMOS refers to an imaging device that has a complementary metal oxide semiconductor LSI design and is manufacturing using CMOS processing technology. Following a concept presentation by E. R. Fossum in 1995 on producing single-chip processors using CMOS image sensors [17] [18], institutions and companies everywhere threw themselves into research and development. Development has been underway with the aim to realize a single-chip camera with built-in DSP (Digital Signal Processing) [19] - [21]. Toshiba gained much attention in 1997 with the release of a digital camera with 330k pixels CMOS sensor. Today, large camera market using CMOS image sensor is formed in the fields of digital cameras, mobile phones and tablets. CMOS sensor has been also replaced from CCD in video camera.

3.1.5 Other Solid-State Image Sensors

(a) MOS type

The world's first MOS type camera was commercialized by Hitachi Ltd. in the 1980s. The difference between the current CMOS-type was not provided with a pixel amplifier. However, it is worth noting that a lot of research results also were applied to CCD. A number of technological developments were carried out, including the npn structure [22], non-destructive readout and half pitch pixel shifting in each scan line [23]. Methods for suppressing fixed pattern noise were also developed [24]. Furthermore, an improvement was also devised in the form of the transversal signal line (TSL) method, in which the signal was read out from the horizontal lines through the use of a horizontal switch transistor [25]. However, it was no match for the low noise of the CCD and soon faded out.

(b) Stacked type

Stacked image sensors improved the aperture ratio by performing photoelectric conversion with an overlaid photoconductive film, using the CCD or MOS sensor only as a switch.

CCD and CMOS sensors have a photodiode for photoelectric conversion, switching and transfer scanning circuits and a semiconductor chip on all the same plane. This means that they have a poor light utilization factor and a low aperture ratio. It was believed that arranging the photoelectric conversion and scanning in a stacked structure would make it possible to configure these independently of each other, as well as to improve the aperture ratio by almost 100%. This research and development was undertaken by Hitachi [26] [27], Matsushita Electric Industrial [28], Toshiba [29] and other manufacturers. As a result, 2M pixel HDTV camera was developed [30] [31] and also used in broadcasting cameras [32].

(c) Amplified type, etc.

Research and development of amplified MOS imager (AMI) amplifying the signal charges converted by the photodiode using MOSFET had been advanced by NHK [32]-[35], Olympus Optical, and Mitsubishi Electric.

Other devices included the charge priming device (CPD) [36], which combined the advantages of the CCD and MOS sensors, the charge sweep device (CSD) [37], an improved version of the CCD, and the accordion CCD [38].

Meanwhile, other research included the static induction transistor (SIT) [39] [40] by Tohoku University and Olympus Optical, which achieved photoelectric conversion with a static induction phototransistor, the charge modulation device (CMD) [41] [42] by the NHK and Olympus Optical, the avalanche photodiode device (APD) [43], floating gate amplifier (FGA) [44] and base stored image sensor (BASIS) [45].

3.2 Image Pickup Tube

Imaging device used in the first video camera in 1974 was Vidicon image pickup tube which used a Sb_2S_3 (antimony trisulfide) photoconductive film. Image pickup tube era continues, but Vidicon had a lag disadvantage. After development for lag reduction, Plumbicon using PbO photoconductive film in photoconductive layer was invented. In response to the stimulus to this, Saticon, Charnicon, and Newvicon were invented one after the

other in Japan.
The Plumbicon was developed in 1962 by Philips. Color quality of the broadcastjng was significantly improved, since the Plumbicon has come to be used in three-tube color camera. In contrast, Saticon, Chalnicon and Newvicon were used in video cameras, resolving the Vidicon lag and also contributing to improved image quality.

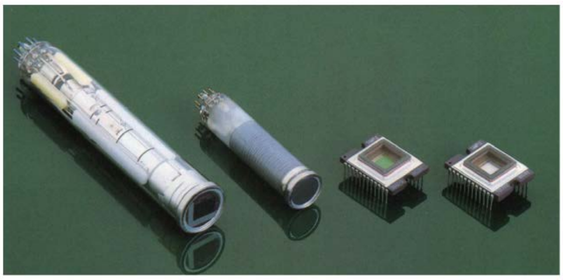


Fig. 3.1 Image Pickup Tube and CCD (46)

Fig. 3.1 shows a comparison of the external shape of CCDs and the image pickup tubes used in single-tube color video cameras (46). 1 inch pickup tube E5180 of the electromagnetic deflection and electromagnetic focusing, 18mm pickup tube of the electromagnetic deflection and electrostatic focusing, one inch color CCD and one inch black and white CCD are shown from left to right. The coil assembly is required to deflect focus the electron beam in the case of an image pickup tube. Since electrostatic-focused image pickup tubes had an built-in focus function, as shown in Fig. 3.2, they did not need an external coil assembly for focusing, which meant they were suitable for downsizing the camera.

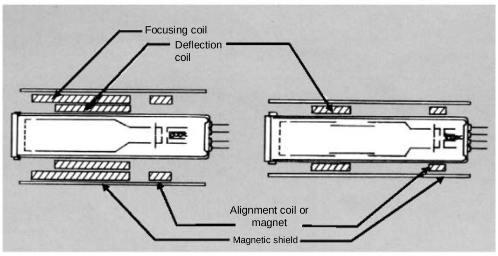


Fig. 3.2 Difference between Electromagnetic Focusing and Electrostatic Focusing (46)

In 18mm image pickup tubes, miniaturization is achieved remarkable when compared with Image Orthicon 4 inch and a half, such as a cannon.
Using Fig. 3.3, let us explain the operation of the image pickup tube, because the reference about the pickup tube is less (47).

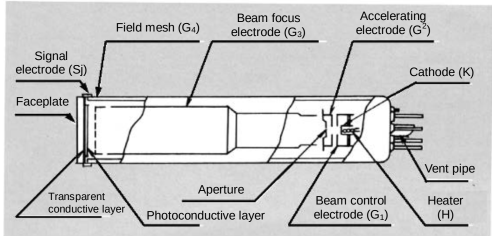


Fig. 3.3 Image Pickup Tube Structure (47)

The faceplate is made of optical glass with the inner surface, coated with a vacuum-deposited ITO (NESA coating) and formed photoconductive layer on the faceplate. The light is incident through the lens from the left, and an optical image is formed on the photoconductive film. A vacuum is maintained on the inside of the image pickup tube. When the photoconductive film is scanned with an electron beam heated by the heater, the signal charge built up by the photoelectric effect according to the optical image is gradually removed from the ITO area. This operation can also be explained by the equivalent circuit given in Fig. 3.4.

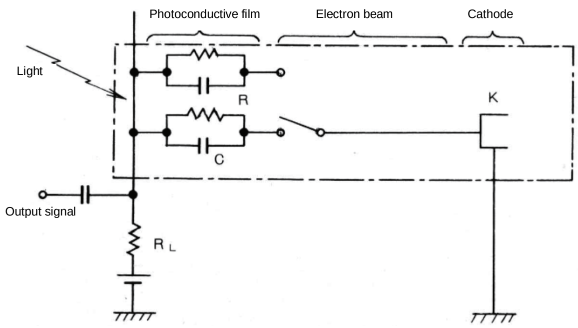


Fig. 3.4 Image Pickup Tube Equivalent Circuit (47)

In order not to mix each pixel, they are required that resistance of the photoconductive layer is large and that the charge stored cannot move laterally.

3.3 CCD

3.3.1 Structure

When CCDs were first invented, research and development was carried out on applications for both semiconductor memory and imaging devices, since they made it possible to store or transfer a signal charge with a simple structure. However, it soon became evident that they offered significant advantages as imaging devices.

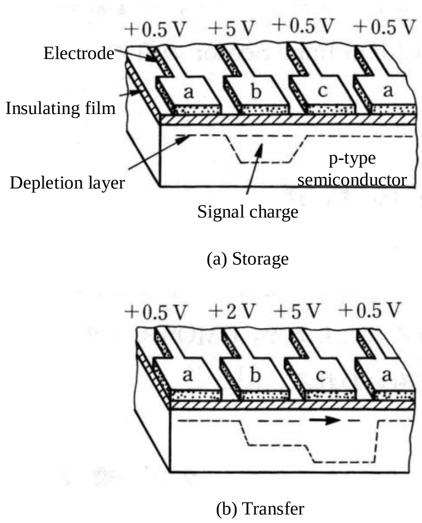


Fig. 3.5 CCD Structure [1]

The basic CCD structure comprises a number of MOS capacitors closely arranged in parallel, as shown in Fig. 3.5. It is a simple structure, with a number of electrodes putting on an insulating layer on the surface of the semiconductor. Applying a voltage to each electrode in sequence allows two operations of transferring and accumulation of the signal.
The electrodes are separated into three groups, a, b and c, with a varying voltage applied to these. In the state of signal accumulation, electrodes a and c are applied with a low voltage of +0.5V, while the electrodes b are applied with a high voltage of +5V. Then, deep potential well is formed under the electrodes b to which a high voltage was applied. If light is exposed in this state, generated signal charge can be accumulated under the electrodes b.
Next, the voltage applied to the electrodes a is maintained at +0.5V and the voltage applied to the electrodes c is altered from +0.5V to +5V, the voltage applied to the electrodes b gradually is changed from +5V to +0.5V, in this case, the potential well change as shown in Fig. 3.5 (b) and the signal charge accumulated under the electrodes b can be transferred under the electrodes c. At this time, the movement in the opposite direction of the signal charge is prevented by a barrier formed below the electrodes a. All signal charges are stored under the electrodes c, when the gradually changed voltage applied to the electrodes b becomes to the +0.5V. If this operation is repeated, the signal charge is transfersed to the right direction. The relationship of the waveforms of three-phase operation which is described above are as in Fig 3.6.

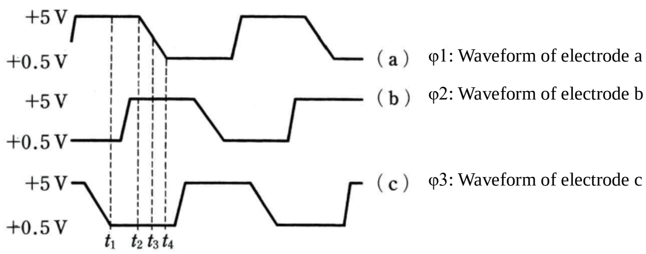


Fig. 3.6 Three-Phase Driving Waveform [1]

Sequentially switching the voltage every third electrode to transfer the signal charge is called three-phase driving. Three-phase driving requires an analog operation from +5V to +0.5V. This cannot be achieved by a binary pulse waveform. In practical CCD, two-phase drive is used for the horizontal transfer, and four-phase drive is used for the vertical transfer.
It was found that the transfer efficiency and S/N cannot be maintained with such simple structures as shown in Fig. 3.5 and a number of specific improvements were made in the CCD structure.

3.3.2 Types of CCD

There are five kinds of CCD imaging devices currently in use, as shown in Fig. 3.7. These comprise five different combinations according to whether a photodiode is provided for photoelectric conversion, whether the CCD itself performs photoelectric conversion and whether it has a one-field CCD memory.
The so-called 2 million pixel CCD has 1920 effective pixels horizontally and 1080 effective pixels vertically, but 4 x 4 pixels, ie, 4 pixels in the horizontal, 4 vertical pixels, are shown for convenience of description. Since the most commonly used among the five types of Fig. 3.7 is IT-CCD, I will try to explain the basic operation of the CCD imaging device using IT- CCD as representative of these.

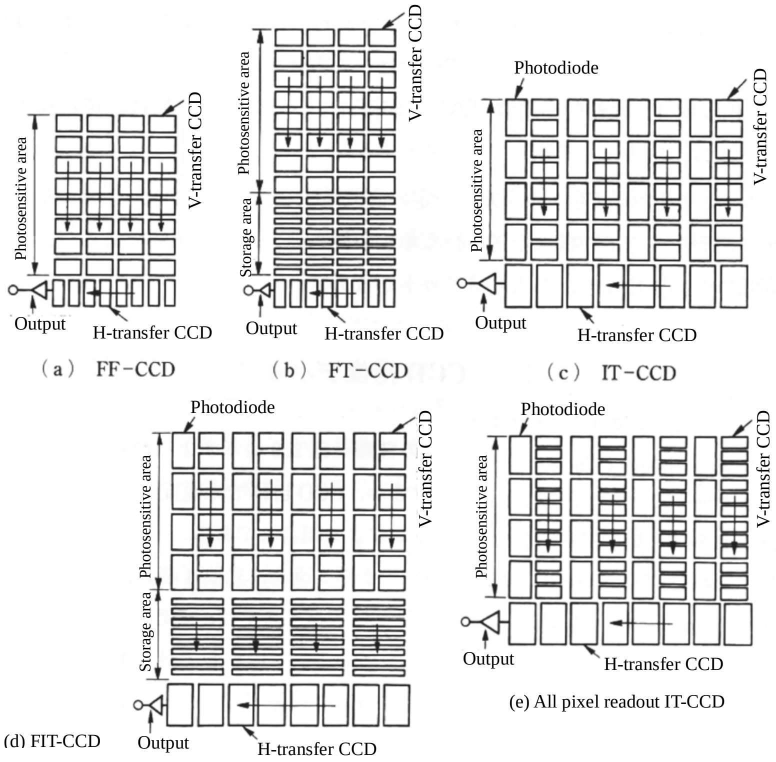


Fig. 3.7 Various Types of CCDs (1)

(a) IT-CCD
Fig. 3.7 (c) shows the structure of the IT-CCD (Interline Transfer CCD). The portrait-oriented rectangles represent photodiodes, while the landscape-oriented rectangles represent the electrodes of the vertical transfer CCDs. The vertical transfer CCDs are arranged between the photodiodes in each row, with the horizontal transfer CCDs arranged in a line adjacent to the last row of vertical transfer CCDs.
When an optical image of an object is formed on the surface by the imaging lens, photoelectric conversion is performed in each photodiode and the signal charge is accumulated, the charge image can be generated.
The charge image signal is sequentially transferred in the vertical and horizontal directions, devised to extract the signal from one signal output terminal. This part is played by the transfer section of the CCD.
The signal charge stored in the photodiodes of the 16-pixel structure is simultaneously transferred to an area of the vertical CCD by a field shift pulse. After two vertical pixels are added, the vertical transfer CCD of four rows is gradually transferring charges in the vertical direction in parallel. The vertically-transferred signal charge is injected into the horizontal transfer CCD. Each time a four-pixel horizontal signal enters, the signal is transferred in the horizontal direction and is output through the output circuit at the left. Once the horizontal transfer CCDs are empty, the signal charges of the next line are fed to the horizontal transfer CCD and the operation is repeated. Signal of one line is gradually obtained from the output terminal in this way. Each photodiode is empty immediately after the charge has been transferred to the vertical CCD by a field shift pulse. Since the light is continued to hit to each photodiode, the charges begin to be accumulated again.
IT-CCD is widely used in video camera, digital camera and almost all of the cameras, except for special applications.
In 1982, when CCDs were first commercialized, the pixel number was about 200,000 (400H x 480V). The size of one pixel was also about 13μm x 22μm. By technological progress, including the miniaturization technology, the size became to the 1.7μm x 1.7μm in 2010.

(b) FF-CCD
Figure 3.7 (a) shows a FF-CCD (Full Frame-CCD), in which the vertical transfer CCDs also perform photoelectric conversion. This format is closest to the original CCD format. This CCD stores and transfers the signal using the same operation as the principle shown in Fig. 3.5. Since light must be incident on the CCD surface, the electrodes of the CCD are formed by transparent electrodes such as poly-silicon.
While the FF-CCD has the simplest structure of all the CCDs, it requires a strobe-type on-off light source or mechanical shutter like a camera, as the light continues to hit during signal transfer. The shutter needs to only be open to let light in during charge storage and then closes to shut off the light for signal charge transfer.
These were initially used in endoscopes and other small cameras as they allowed the chip size to be reduced, but are hardly used today.

(c) FT-CCD
Figure 3.7 (b) shows a FT-CCD (Frame Transfer CCD), which has a CCD 1 field memory unit between the horizontal transfer CCD and photosensitive portion of the FF-CCD. The signal charge for the entire field stored in the photosensitive portion has to be quickly transferred to the storage unit, preventing light hitting in during transfer. The FT-CCD has been studied actively at an early time of CCD invention, but for the reason that the chip size is large and that inevitable smear phenomenon due to the leakage of light exists, the opportunity to be used in Japan

is small.

(d) FIT-CCD
Figure 3.7 (d) shows a FIT-CCD (Frame Interline Transfer CCD), which is added the one field CCD memory to IT-CCD. Although chip size is larger than the IT-CCD and complicated two types of vertical transfer are required, FIT-CCD is possible to reduce the smear which is a disadvantage of IT-CCD. Accordingly, FIT-CCDs are used in electronic news-gathering (ENG) cameras and studio cameras for performance-oriented broadcasting stations. At present, 2/3 inch FIT-CCD having 2 million pixel and S/N 62dB performance is used in mainstream broadcasting camera.

(e) All-Pixel Readout IT-CCD
Figure 3.7 (e) shows an all-pixel readout IT-CCD, which has a structure with three to four vertical transfer CCD electrodes per photodiode, thereby allowing the signals from all the photodiodes to be read out at the same time.

3.3.3 CCD Structure

Figure 3.8 shows a cross-sectional structure of the typical pixel structure used in IT-CCDs. The photosensitive portion is provided under the micro-lens, a vertical transfer unit is disposed on the right side. Japanese inventions are shown as a part surrounded by the red bold frame which had a significant effect on the performance improvement.

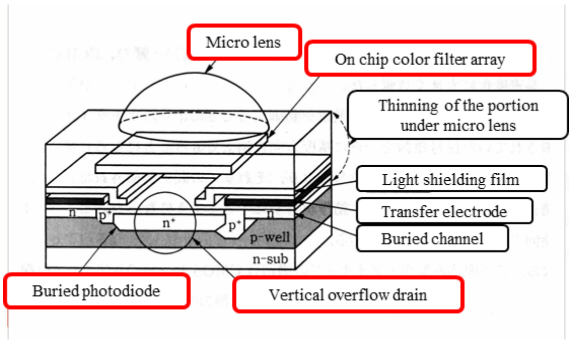


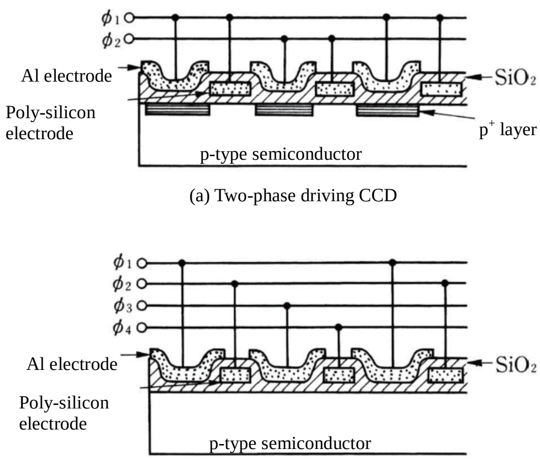
Fig. 3.8 IT-CCD Pixel Structure [48]

Although the principle of CCD is illustrated in Fig. 3.5, the structures put into practical use has become fairly complex structure to improve the performance.

(a) Photodiode
A photodiode used in CCD is made to form a p-well on a semiconductor substrate n, to form an n^+ layer on it, so-called n^+ pn structure.
In addition, it is characterized in that the p^+ layer is formed on the n-type layer, and is formed in the bulk side slightly rather than the surface of the photodiode, called a buried photodiode. The structure has a $p^+ n^+$ pn from the surface as $p^+ n^+$ pn. Using this structure, a photodiode surface can be so as not to deplete, and dark current that tends to occur at the interface is suppressed to lower. Fixed pattern noise due to dark current is suppressed to lower one digit or more.
On the other hand, by reducing the thickness below the photodiode, to create a pn structure in the direction of the substrate, p-well has been devised structure as cast off the substrate side of the signal charge generated excessively strong light. Thus, it is possible to suppress the blooming, and further, to be able to be efficiently accumulated a visible light component. Because charges by long wavelength light are extinguished, since long-wavelength light such as near-infrared light is converted in deep p-well portion to reach. This structure is called a vertical overflow drain (VOD) structure and has contributed significantly to the high-densification and miniaturization of the CCD.
The use of this structure makes it possible to remove the signal charge stored on the photodiode all at once along the substrate by controlling the substrate voltage. A system of adding a pulse at any given time to remove previously stored signals has made electronic shutter operation easier. It should be noted that the structure of the buried photodiode is also used in the CMOS image sensor.

(b) Color Filter
Micro-lens and color filter array are formed on the photodiode.
Unlike ordinary semiconductor technology, the new technologies are needed to stain and process using a special resin.
This is called an on-chip color filter, where the color filter array is precisely aligned with the CCD pixels, being overlaid onto the pixels at micron level.
The micro-lens array is formed on top of this. The micro-lens concentrates the light on the photosensitive surface onto the photodiode portion, which can double or triple the amount of light entering the photodiode, thereby significantly improving the light efficiency, which was a drawback with the CMOS and IT-CCD image sensors. It also helps to increase sensitivity and offers the advantage of a light-shielding effect to reduce the amount of light to the transfer electrodes and transistor area.

(c) Transfer Electrode
When a field shift pulse is applied to the transfer electrodes, signal charges stored in the buried channel photodiode in the transfer unit is transferred via the p+ layer formed to the right of the photodiode.
The transfer unit is structured to minimize light contamination. It comprises Poli-Si electrodes through a SiO_2 insulating film in the the buried channel n, which is then covered with an aluminum shielding layer through an insulating membrane.

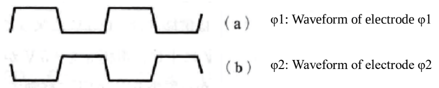


(a) Two-phase driving CCD

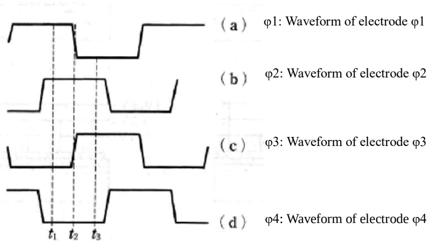
(b) Four-phase driving CCD

Fig. 3.9 Cross-Sectional Structure of Horizontal and Vertical Transfer CCDs [1]

(d) Transfer Direction Structure
Figure 3.9 shows the structure of a horizontal transfer CCD for two-phase driving and a vertical transfer CCD for four-phase driving.
The overlapping electrode structure prevents any unnecessary barriers from occurring. Since a p+ layer forms under one electrode in two-phase driving, forming a potential barrier, transfer in one direction is possible.
The respective waveforms are shown in Fig. 3.10.
Two-phase driving is used for horizontal transfers, which require high speed, while four-phase driving is used for vertical transfers, which can be carried out at a relatively slow speed.



(a) Waveform of two-phase driving CCD

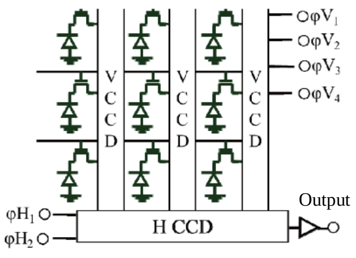


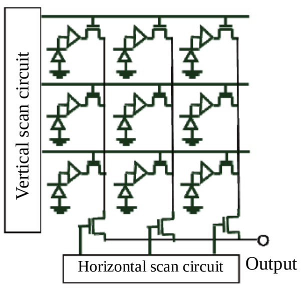
(b) Waveform of four-phase driving CCD

Fig. 3.10 Waveforms of two-Phase and four-Phase Driving [1]

3.4 CMOS Image Sensor

As described in 3.1.4, CMOS image sensors have attracted attention from around 1995. As shown in Fig. 3.11, as compared with the IT-CCD in terms of the configuration of the imaging device, it is possible to see the difference in the method for reading to the output circuit signal charges photo-electrically converted by the photodiode.





(b) CMOS image sensor

Fig. 3.11 CMOS Image Sensor Structure

As shown in Fig. (b), the signal charge stored in the photodiode is amplified by an amplifier provided for each pixel, then switched and read out for each pixel by the vertical and horizontal shift resistors.
Although Fig. (b) shows an example of a CMOS image sensor constituted by two transistors, four transistors are mainly used recently to improve performance.

3.4.1 Pixel Structure
Figure 3.12 shows a pixel configuration of the so-called 4TR composed of four transistors [49].

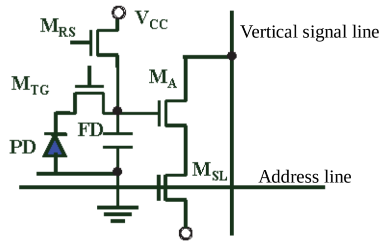


Fig. 3.12 4TR Pixel Structure

One pixel of the CMOS sensor is composed of a photodiode PD, a readout transistor M_{TG} (transfer gate transistor), an amplifier transistor M_A, a select transistor M_{SL} and a reset transistor M_{RS}.
The signal charge generated by photoelectric conversion is stored in the source of the readout transistor M_{TG}. The accumulated charge switches on when a pulse is applied to the gate, and is pooled in the floating diffusion FD. When a line is selected by the select transistor M_{SL}, the signal amplified by the amplifier transistor M_A is transferred to the vertical signal line. The vertical and horizontal shift resistors then output the signal in sequence.
Here, it is intended that the reset transistor is placed between the amplifier transistor and the readout transistor; this initializes the voltage to a constant level before the signal is read out.

3.4.2 Characteristics
Having an amplifier in each pixel in the CMOS sensor made it possible to overcome the noise, which was the greatest drawback with the existing MOS sensor. While it had always been the intention to provide an amplifier for each pixel, any variations between the amplifiers would result in fixed noise, making the entire sensor useless.
Advances in semiconductor microfabrication played a significant part in enabling the production of elements with uniform amplification. Also advances in circuit technology for electronically correcting pixel defects and noise contributed to this.
Post-processing also became possible using a digital signal through a system called column ADC, wherein the signal charges for each horizontal line are AD converted all at once. This was a significant step forward for camera performance.
Another major feature of the CMOS image sensor is the capability to quickly output the signal charges obtained by photoelectric conversion.

3.4.3 Product of the CMOS Image Sensor
The first product using CMOS image sensor was a digital camera PDR-2 commercialized in 1997.
CMOS sensors have grown significantly as a digital camera imaging devices since then. Quite a number have also been used in mobile phones. As a video camera, it

began to be used in HDTV camera required many pixels.

3.5 Comparison of CMOS Image Sensor and CCD

As mentioned thus far, the golden age of the CCD as an imaging device for video cameras is coming to a close as these are now being replaced by CMOS image sensors. Since technical details are beyond the scope of this report, let us simply make several comparisons between CMOS sensors and the mainstream consumer IT-CCD sensor, with reference to the works cited in the preface. Through this, the reason why the CMOS sensor has been growing by leaps and bounds will be appreciated.

(a) Characteristics and Features

Table 3.2 illustrates the distinctive characteristics of each sensor. From the fact that CMOS image sensor is effective for the integration of the peripheral circuit of low power consumption, such as DSP, it is useful to the camera-equipped mobile phone small and became main product in this field.

Table 3.2 Features of CCD and CMOS Image Sensors

	CMOS image sensor	CCD
Photoelectric conversion	Photodiode	Same as left
Amplifier	Each pixel	One in the output stage
Readout	Column	CCD transfer
Smear	No	Yes
Output	Digital	Analog
FEA	Built-in	Separate chip required
Signal processing circuit	Can be built in	Not possible
Power source	1 power source	3 power source

Table 3.3 illustrates the distinguishing features of both sensors. The initial drawbacks of high noise and low sensitivity has led to improvements that make it comparable to the CCD sensor. While CCD smear has been improved by 70-90dB, this phenomenon inherently does not occur in the CMOS sensor. Advantage of the CMOS sensor has become decisive in the number of pixels of two million pixels or more. There is a theory that imaging devices have a 30-year cycle and the CCD, invented in 1970, finally appears to be vacating the leading role.

Table 3.3 Performance Comparison of CCD and CMOS Sensors

Item	CMOS image sensor	IT-CCD
Sensitivity	◎	◎
Smear	◎	△
Dynamic range	○→◎	○
Pixel increase	◎	△
High speed	◎	○
S/N	○→◎	◎

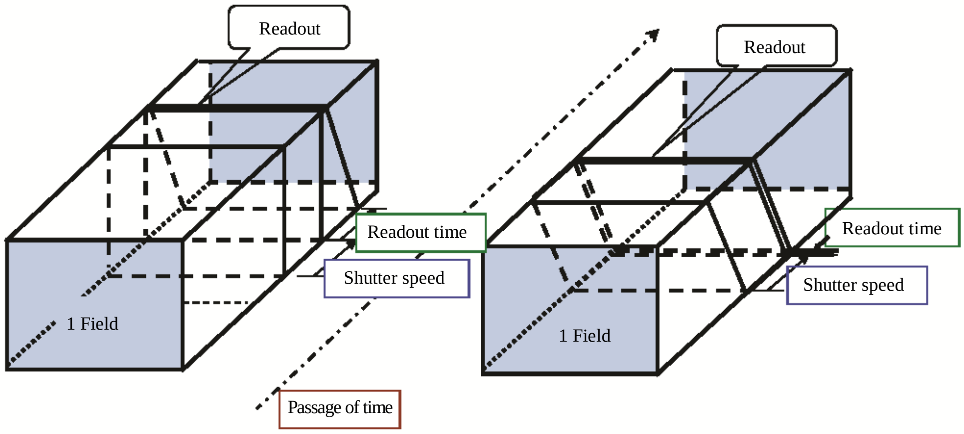
(b) Readout Methods - Global Shutter and Rolling Shutter

There is a difference between CCD and CMOS image sensor in the method of reading the signal charge accumulated in the image portion. I will try to explain the difference between these reading methods.

In the CCD, by a field shift pulse, the signal charge accumulated in all pixels are transferred to the V-CCD at once, and read out. This method is called a global shutter. By contrast, in a CMOS image sensor, the signal charges are read out line by line. This method is called a rolling shutter. Let us examine the differences between these readout methods in detail, with reference to Fig. 3.13 [50] [51]. In the figure, the time axis extends backwards from the surface of the paper. The optical image reaches the imaging plane of the sensor in a series of continuous images over time. The readout methods differ in the way to sanple this continuous image, that is, where the moving image is cut into frames.

Figure (a) shows the CCD readout method, in which the shutter is opened at a specific time and closed again after the signal is stored. Since this is uniform everywhere in all the pixels, the accumulation is terminated at the time when it will be cut vertically along the time axis, a predetermined time has elapsed. Then, simultaneously, the signal charges are transferred to the V-CCD. Since the charges are read sequentially line by line in the V-CCD, over time, it will read out the signals sequentially obliquely. Figure (b) shows the CMOS sensor readout method, in which the signal appears cut on an angle over time, as the shutter opens line by line across all the pixels. Since the shutter interval is constant for all pixels, the signal is gradually integrated over a period of time within the time interval. The signal is then sequentially read out on the diagonal, as it is read out sequentially line by line. This means that the CCD sensor shoots one frame at a time, while the CMOS image sensor uses a continuous shooting method. Accordingly, the CMOS image sensor readout method makes perfect sense for capturing a moving image, but this is not the case for extracting a single frame. When shooting a moving subject, instead of capturing a scene comprising all of the pixels at the same time like the CCD sensor, the CMOS image sensor captures different images of the scene on each line across all of the pixels. This can result in image distortion if the subject is moving at high speed. This requires some attention in the case of digital cameras intended for taking still images.

On the other hand, CCD becomes disadvantageous if you want to read without delay. As can be seen from in Fig. (a), time delay occurs in the form of a triangle to read the signal from the storage end. Meanwhile, delay does not occur until signals readout time from the accumulation end in the CMOS sensor, as is clear from Fig. (b). In normal standard television formats, the base of the triangle in the CCD sensor figure is one field time of 1/60s or 16.6ms. The longest delay in a CMOS sensor is one line time of 0.031μs, that can be almost ignored time delay. While this difference in readout time is not a significant problem in a video camera, it is a very important factor in the time-sensitive scene, where the captured images have to be processed quickly, such as in an automotive camera.



(a) CCD Readout Method (B) CMOS Imager Readout Method

Fig. 3.13 Differences in Readout Methods [50][51]

(c) Trend of Miniaturization of Pixel Pitch

Fig. 3.14 shows a trend in pixel pitch reduction. When video cameras were first put to practical use in 1980, they had a pixel pitch of 12μm. By around 1995, most cameras had square pixels with a pitch of 5.6μm. Miniaturization then was temporarily stagnant, but then continued to progress from the late 1990s.

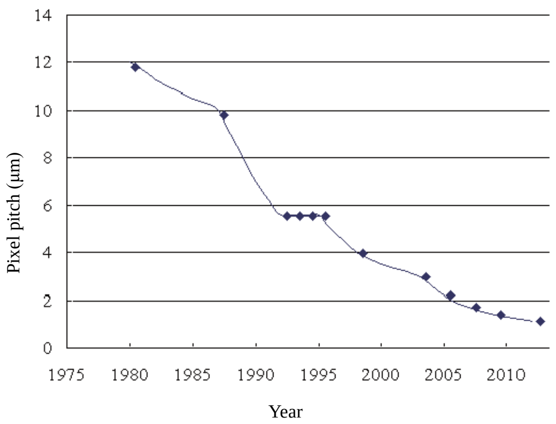


Fig. 3.14 Trend in Pixel Pitch Reduction

It was previously thought that a camera could not be made using a sensor with a pixel pitch of 2.2μm or less. Because the pitch becomes close to the wavelength of light and decreases the imaging performance due to lens diffraction and other effects. However, the advancement of technological development led to the commercialization of a CMOS image sensor having with a 1.12μm pixel pitch in 2012.

If the pixel pitch can be reduced, the chip size can also be reduced if the pixel number is constant. It is then possible to place a large number of chips on one semiconductor wafer. This makes it an effective means for cost reduction. By contrast, the smaller the pixel size, the smaller the amount of incident light on the pixel and the amount of signal is reduced. As a result, the sensitivity decreases and the S/N ratio also decrease. However, these issues have been surmounted by the advancement of technological development.

3.6 Important Imaging Device Technologies

3.6.1 Chronology of Main Technologies

Number of major imaging device technologies for improving performance and establishing for mass production have been developed in Japan. Table 3.4 shows important technology items and the explanation by era. Technical details can be found in the cited references.

3.6.2 Important technology viewed from the patent and Society report

Since research and development have been performed by verifying the Society report and patent, let us introduce a few of these.

The Japan Patent Office published a Patent Application Technology Trends Research Report on digital cameras [52] in 2009.

(a) VOD Technology

VOD is the structure shown in Fig. 3.8. It was significantly beneficial to improve the image quality and function by providing an electronic shutter and suppressing blooming.

As shown in Table 3.5, the VOD was invented by Tetsuo Yamada (then of Toshiba), who was awarded the Minister of International Trade and Industry Invention Award and the National Invention Awards by this invention. He invented 1 more related patent and was awarded the Director General of the Science and Technology Agency Invention Award and the Kanto Region Commendation Invention Awards.

VOD technologies have been published in the Journal of the United Kingdom and Electronics Engineers by H. Goto, T. Yamada and et al [53]. On the other hand, Y. Ishihara presented at ISSCC similar techniques also reported domestic Japanese ITE.

(b) FIT-CCD Technologies

A FIT-CCD is a CCD with a one-field memory, as shown in Fig. 3.7 (d). Smear is reduced significantly, FIT-CCD is used almost to the broadcasting CCD camera. For the chip size becomes larger, since the cost increase, it has been rarely used in the video camera. The FIT-CCD was invented by Sekine, as shown in Table 3.6, but although a

patent was applied for, the patent was not registered as no review request was made. Instead, the patent rights went to Ishihara of a subsequent application.
It should be noted that the cited papers by Kenju Horii are old [(56)-(58)].

Table 3.4 Chronology of Imaging Devices

Year	Name / Manufacturer	Name	Remarks
1947	J. Bardeen and W. H. Brattain (Bell Labs)	Transistor	
1963	Morrison (Honeywell)	Photo scanner[61]	
1963	F.M. Wanlass (Fairchild)	Invention of CMOS image sensor	1963 IEEE ISSCC USP 3356858
1964	J.W.Horton	Scanistor[62]	The idea of making an imaging device by reading photodiodes in order side-by-side
1964	P.K.Weimer	Thin film image sensor array	The idea of making an imaging device by reading thin-film elements in order side-by-side [63]
1968	Plessy Company Ltd.	PN Photodiode + MOS Amp [64]	CMOS image sensor principle
1969	F. L. J. Sangster	BBD [6]	Type of CTD, invented one year earlier than the CCD
1970	W. S. Boyle and G. E. Smith	CCD[4][5]	Invention of the CCD
1971	Philips	CID[7][8]	
1971	M. F. Tompsett, et al	FT-CCD[65]	First CCD area image sensor
	W. F. Kosonocky and J. E. Carnes	Floating diffusion amp [66]	
	R.H.Krambeck et al.	Two-phase driving CCD [67]	Used in horizontal transfer
1972	W. F. Kosonocky and J. E. Carnes	IT-CCD[68]	Main consumer CCD
	R. H. Walden et al.	Buried channel CCD [69]	
	C. H. Sequin	Horizontal OD (Overflow Drain) [7]	
1974	M. H. White, et al	CDS (Correlated Double Sampling)	Correlated double sampling circuit [70]
	A. Yusa et al. (Olympus)	MOS type BCD (Bulk Charge Transfer Device) [40]	Similar technology to buried channel CCD
1975	Y. Yoshino et al. (Panasonic)	Three-level drive [91]	Driven by the same electrode as the transfer electrode and the readout electrode
1976	S. Ochi (Sony)	Field readout CCD[71]	
1978	T. Yamada (Toshiba)	VOD (Vertical Overflow Drain) [53]	Invention of VOD
	H. Sekine (Toshiba)	FIT-CCD [63][64]	Invention of FIT-CCD
1979	N. Koike et al. (Hitachi)	MOS type npn structure[22]	
	Hitachi	Stacked MOS device[26][27]	
	Tohoku Univesity & Olympus	SIT[39],[40]	Photoelectric conversion in the static induction transistor
1980	Ohba et al. (Hitachi)	Fixed pattern noise reduction method [24]	Development of FPN method
	T. Chikamura et al. (Panasonic)	Stacked CPD[27][28]	
	S. Manabe et al. (Toshiba)	Stacked CCD[29]-[32]	
	Panasonic	CPD[36]	Invention of Charge Priming Device
	NEC	Intrinsic gettering (IG) [74]	
1981	N. Teranishi (NEC)	Buried photodiode[72][73]	Same technology named the pinned photodiode by B. C. Burkey [3]
	Y. Takemura et al. (Toshiba)	Sweep-out drive technology [90]	Technique to erase the residual charge by driving with a pulse number greater than the number of pixels
1982	T. Kuroda et al. (Panasonic)	Depletion of the photoelectric conversion element at the time of reading [92]	Removal of residual charge
	Hitachi	MOS type pixel interpolation method[23]	
1983	S. Ochi (Sony)	The pixel shift method [75]	Technique for increasing the resolution by shifting 1/2 pixel pitch on each scan line
	H. Sekine (Toshiba)	Checkered pixel array [76]	Idea of the honeycomb patent

	Y. Ishihara (NEC)	On-chip μ lens [59]	
	Sony	MCZ substrate [77]	
1984	A.J.P.Theuwissen et al. (Philips)	Accordion CCD [38]	
1985	Hitachi	MOS TSL method [25]	Performance improvement [33](Signal reading method by providing a horizontal switching transistor for each pixel)
1985	Mitsubishi Electric	CSD (Charge Sweep Device[37]	CCD improvement
	Olympus	CMD (charge modulation device) [41][42]	
	F. Ando et al (NHK)	AMI (Amplified MOS intelligent imager) [33]-[35]	Method for amplifying MOSFET in the signal charges photoelectrically converted by the photodiode
1988	J.Hynecec	FGA (floating gate array) [44]	
1990	Panasonic	APD (avalanche photodiode device) [43]	
1991	Toshiba	2 million pixel stacked CCD for HDTV [29]-[32]	
1993	E. R. Fossum	Active CMOS image sensor proposed[16]	
	NEC	All pixel readout method	Progressive scanning [78]
	U. Seger	WDR[83]	
1995	E. R. Fossum	1 chip camera with built-in DSP [17][18]	DSP : Digital Signal Processing
1996	C. H. Aw	Global shutter[84]	
1997	D. Scheffer	Active Pixel Image Sensor [81][82]	
2000	T. Sugiki et al. (Toshiba)	Parallel ADC [84]	Providing ADC for each line and pipelining the ADC and data output
	N. Nakamura & S. Matsunaga (Toshiba)	CMOS noise reduction method [85]	1/f noise and thermal noise suppression using a feedback clamp method on the output amplifier itself
	T. Yamada (Fuji Film)	Honeycomb CCD [86]	
2001	Pixim	WDR by providing an ADC in each pixel	WDR with image processing
2003	K. Oda et al. (Fuji Film)	Honey comb WDR [87]	
2005	S. Sugawa (Tohoku University)	WDR	Horizontal overflow storage capacity [88]
2007	Y. Egawa (Toshiba)	WDR	Using double exposure [89]
2008	OmniVision-TSMC	Backside illuminated CMOS-APS	For cellular phones
2010	Sony	16.41million pixel back illuminated CMOS-APS	For video cameras
	Toshiba	14.6million pixel back illuminated CMOS-APS	For cellular phones
	Canon	120 million pixel CMOS-APS	The largest number of pixels: 9.5 field/s

Table 3.5 VOD Technologies

Item	Charge Transfer Device	Solid-State Image Sensor	Solid-State Image Sensor	Solid-State Image Sensor	Solid-State Image Sensor and Driving Method	Solid-State Image Sensor	Solid-State Image Sensor and Production Method
Inventor	Hiromitsu Shiraki	Iwao Takemoto	TetsuoYamada	Tetsuo Yamada et al.	Yasuo Ishihara	Nobukazu Teranishi	NobukazuTeranishi
Manufacturer	NEC	Hitachi	Toshiba	Toshiba	NEC	NEC	NEC
Appl. No.	S49-134668	S52-5953	S53-1971	S55-100346	S55-13057	S56-57999	S57-8433
Filing date	Nov. 21, 1974	Jan. 24, 1977	Jan. 13, 1978	July 22, 1980	Sep. 19, 1980	April 17, 1981	Jan. 22, 1982
Publication No.	A S51-60186	A S53-91622	AS 54-95116		AS 57-55672	AS 57-173274	AS 58-125970
Publication date	May 25, 1976	Aug. 11, 1978	July 27, 1979		April 2, 1982	Oct. 25, 1982	July 27, 1983
Public notice No.	B S61-60592	B S58-23992	BS 59-17581	BS62-17878	BS62-16599	BH1-21351	BH4-24870
Public notice date	Dec 22, 1986	May 18, 1983	April 21, 1984	April 20, 1987	April 13, 1987	April 9, 1992	April 28, 1992
Patent No.	1430947	1211101	1243180	1411948	—	1932139	1925337
Date of patent	March 24, 1988	June 12, 1984	Dec. 14, 1984	Nov. 27, 1987	—	May 26, 1995	April 25, 1995
Decision of refusal	May 8, 1984	July 6, 1982			Nov. 29, 1988	Feb. 14, 1989	
Appeal trial	S59-10283	S57-15970				S1-4536	
Demand for trial	June 7, 1884	Aug. 4, 1882				March 16, 1989	
Joint names		Norio Koike Masaharu Kubo		Nobuo Suzuki Hiroshige Goto		Yasuo Ishihara Hidetsugu Oda	Hidetsugu Oda
Remarks	pn structure FT-CCD	p-well MOS image sensor	1990 Minister of International Trade and Industry Invention Award at the National Invention Awards. 1989 Director General of Science and Technology Agency Invention Prize at the Kanto Invention Awards.			Change in the diffusion depth of the N-type region	Impurity variation suppression of CZ board

Reference Materials
(1) Nobukazu Teranishi: [Memorial Lecture] Technological Developments towards Practical Image Sensor Implementation: Evolution of the Vertical Overflow Drain (VOD), ITE-IST, Nov. 19, 2010.
(2) Japan Patent Office: Industrial Property Digital Library.

The following are related papers.

(1) Hiroshige Goto, Hirokazu Sekine, Tetsuo Yamada and Nobuo Suzuki: CCD Linear Image Sensor with Buried Overflow Drain Structure, Electronics Letters, Vol. 17, No. 24, pp. 904-905, 1981.
(2) Y. Ishihara, E. Oda, H. Tanigawa and N. Teranishi: Interline CCD Image Sensor, with Anti-blooming Structure, ISSCC82 Digest of Technical Papers, pp.168-169, Feb.1982.
(3) Yasuo Ishihara et al.: CCD image sensor with a Vertical Overflow Drain Structure, ITE Journal, Vol.37, No.10, pp.782-787, 1983.
(4) Y. Hiroshima, S. Matsumoto, K. Senda, T. Kuriyama,K. Horii, T. Kuroda, T. Kunii, H. Mizuno: Elimination of Fixed Pattern Noise in Super-8 Format CCD Image Sensor by the Use of Epitaxial Wafers, IEEE IEDM, PP.32-35 (Dec. 1984).

(c) On-Chip Micro-Lens

The on-chip micro-lens has a structure as shown in Fig. 3.8. By concentrating the optical image efficiently on the photodiode, micro-lens is very effective in improving the sensitivity. As shown in Table 3.7, the literature of Ishihara is the first in the conference presentation [(59)]. Invention of Wada et al. is the basic patent. In the field of discrete components, techniques for collecting light have been carried out using a small lens on the device for a long time. However, various improvements were required to be formed micro-lenses without defect using a heterogeneous resin on a CCD semiconductor substrate.

(d) Addition Readout Method

For interlaced scanning is performed in the moving image, it is necessary to devise the reading method of each line. In order to eliminate lag disadvantage, method of adding the two adjacent line signals become effective.

Although the basic patent for this method was filed by RCA, immediately after this patent has become known, domestic manufacturers have also been proposed many patents, as shown in Table 3.8.

For interlace technology there is a paper by CH Sequin [(60)].

Table 3.6 FIT-CCD

Item	Solid-State Image Sensor	Charge Transfer Image Sensor and Driving Method	Solid-State Image Sensor
Inventor	Hirokazu Sekine	Yasuo Ishihara	Shigeyuki Ochi
Manufacturer	Toshiba	NEC	Sony
Appl. No.	S53-125703	S54-72035	S54-83455
Filing date		June 8, 1979	July 3, 1979
Publication No.	Oct 14, 1978	AS 55-163963	AS 56-8966
Publication date	AS 55-52675	Dec. 20, 1980	Jan. 29, 1981
Public notice No.	April 17, 1980	BS 60-33345	BS 62-52988
Public notice date	-	Aug. 2, 1985	Nov. 9, 1987
Decision of refusal	-		Nov. 14, 1989
Appeal trial			Dec. 14, 1989
Patent No.		1309974	1615692
Date of patent	-	March 26, 1986	Aug. 30, 1991
Remarks	First proposal of FIT-CCD Patent not granted due to forgetting to request review	Not aware of prior application by Sekine	Objection on the grounds of the prior Sekine application Appealed after refusal In response to the reasons for refusal, registered again with limited claims Name also changed FIT-CCD with electronic shutter function

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(1) Kenju Horii, Takao Kuroda, Shigenori Matsumoto and Takao Kunii: A New CCD Imaging Device Configuration: the FIT-CCD Image Sensor, 1981Kansai-section Joint Convention of Institutes of Electrical Engineering G9-14, pp. G280.
(The first mention of the name FIT-CCD to refer to the FIT-CCD structure.)

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(The term FIT does not appear, but the actual FIT-CCD is illustrated.)

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(Full paper on FIT-CCDs).

Table 3.7 Micro-Lens

Item	Photoelectric Conversion Device	Receiving Equipment for Optical Warning Device	Solid State Image Device and Production Method	Imaging Device	Micro-Lens Production Method	Solid State Imaging Device and Production Method	On-Chip Lens Production Method
Inventor	Shigeo Kobayashi	Takashi Yamamoto	Takamichi Wada et al.	Masatoshi Sato	Toshio Nakano et al.	Tetsuo Aoki	Shingo Kadomura
Manufacturer	Panasonic	Panasonic	Panasonic	Fuji film	Hitachi	Sharp	Sony
Appl. No.	S47－128724	US50-46170	S51-151123	S54-31974	S58-168165	H5-241030	H7-158845
Filing date	Dec. 20, 1972	March 31, 1975	Dec. 15, 1976	March 19, 1979	Sep. 14, 1983	Sep. 28, 1993	June 26, 1995
Publication No.	AS49-84797	UAS51-124360	AS53-74395	AS55-124366	AS60-60755	AH7-99296	AH9-8266
Publication date	Aug. 14, 1974	Oct. 7, 1976	July 1, 1978	Sep. 25, 1980	April 8, 1985	July 9, 1999	Jan. 10, 1997
Public notice No.	-	-	PS60-59752	-	-		-
Public notice date	-	-	Dec. 26, 1985	-	-		-
Patent No.	Reject	Reject	1336494	Reject	Withdrawal	2950714	3355874
Date of patent	-		Sep. 11, 1986	-	-	36350	Oct. 4, 2002
Decision of refusal	July 20, 1980	May 8, 1979	Jan. 22, 1985	Oct. 20, 1987			
Appeal trial			Feb. 21, 1985				
Remarks	Close contact with a convex lens on top of the sensor	Visible light cut-off filter on the light-receiving element covered in a spherical shape	Joint signatories as follows: Yasuaki Terui, Yu Yoshino and Yoshio Ohta; Emmy Award		Joint signatories as follows: Akira Sasano, Ken Tsutsui and Toshihisa Tsukada	Production method providing a convex lens, flat layer and a concave lens.	
Reference patent			AS49-84797 US51-124360				AH3-190166 AS60-60755 AH7-99296 AH2-244625

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Table 3.8 Addition Readout

Item	Method of Operation of Charge Transfer Type Image Sensing Device	Solid-State Imaging Device	Solid-State Color Imaging Device	Solid-State Imaging Device	Solid-State Imaging Device	IT-CCD Imaging Device	Solid-State Color Imaging Device
Inventor	P.A. Levine	Yoshio Ohta	Yoshio Ohta	Shusaku Nagahara	Yoshio Ohta	Shigeyuki Ochi	Norio Koike
Manufacturer	RCA	Panasonic	Panasonic	Hitachi	Panasonic	Sony	Hitachi
Appl. No.	US 491836	S49-131701	S50-82996	S51-71142	S51-154017	S51-157234	S52-82965
Filing date	1974/7/25 Priority	1974/11/14	1975/7/4	1976/6/18	1976/12/20	1976/12/24	1977/7/13
Publication No.	AS51-36819	AS51-57123	AS52-6416	AS52-155010	AS53-77125	AS53-80119	AS54-37427
Publication date	1976/3/27	1976/5/19	1977/1/18	1977/12/23	1978/7/8	1978/7/15	1979/3/19
Public notice No.	PS54-41363	-	PS58-14789	PS60-43704	PS60-28435	PS62-40910	PS58-53830
Public notice date	1979/12/7	-	1983/3/22	1985/9/30	1985/7/4	1987/8/31	1983/12/1
Patent No.	1003021	Withdrawn	1185619	Trial rejected	1306183	1522884	123058
Date of patent	1980/6/27	-	1984/1/20	-	1986/3/13	1989/10/12	1984/9/19
Decision of refusal				1984/8/28		1985/7/25	
Trial number				S59-17716		S60-17670	
Demand for trial				1984/9/25		1985/8/29	
Remarks	Fundamentals of addition pixel readout	Describes a method of reading out multiple lines at once during one horizontal readout					
Joint signatories			Ryuhei Nakabe Toshiro Matsuura	Hideo Onodera Kenji Takahashi Kazuhiro Sato	Yasuaki Terui Takamichi Wada Yu Yoshino		Iwao Takemoto Masaharu Kubo Kazuhieo Sato Shusaku Nagahara
Reference Patent			AS51-29021	AS51-31119 AS51-36819	AS51-36819	AS51-57123 AS52-155010 AS53-77125	AS52-6416 AS52-2403

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4. Color Imaging Systems - Part 1 Image Pickup Tube Era

4.1 Overview

Many kinds of image devices have been used for the video camera as follows. Image pickup tube has been used for a long time from the 70's to the first half of the 80's. Next, CCD has been used from the late 80's to the early 2000's and CMOS image sensor has been used since 2000's. All of these are photoelectric conversion devices that sense the brightness of the light and alter the magnitude of the electrical signal.
This is because the elements that perform the photoelectric conversion, whether it is the photoconductive layer in the image pickup tube or the photodiodes in the CCD or CMOS image sensors, have no light wavelength selectivity and are sensitive to any wavelengths in the visible light region.
Therefore, some optical means of separating the input light into three primary colors was necessary to obtain three primary color signals. To date, a lot of research and development have been conducted for this technique (1).
Color pick up systems can be expressed as in Fig. 4.1, when they can be classified by the number of imaging devices. While image pickup tube devices can be either single-tube or three-tube and solid-state imaging devices can be either single-chip or three-chip, only the chip types are shown here to simplify the illustration.
The format shown in Fig. (b) is used in almost all video cameras, while the format shown in Fig.(c) is used in some special applications.
The sequential format shown in Fig. (a) became a hot topic in TV video transmission of the Apollo moon landing. This method is practical for business use and some other medical applications.
Meanwhile, the three-chip shown in Fig. (c) is used in studio cameras for broadcasting stations that require high performance, ENG (electronic news gathering) cameras and EFP (Electronic Field Production) cameras.
Since this report is mainly providing a chronological overview, refer to the cited literature (1) (2) for technical details.

4.2 Single-Tube Method

Before the CCD was put to practical use, most video cameras used the Vidicon, a camera tube with a Sb_2S_3 (antimony trisulfide) photoconductive layer.
In image pickup tube, photoconductive layer is scanned by the electron beam, and signals are extracting from the transparent electrodes. Electron beam scanning and convergence was performed through analog methods, usually by electromagnetic deflection and convergence using a coil. Accordingly, scanning uniformity was difficult to achieve and scanning distortion would occur, meaning that the scanning position could not be determined exactly and accessing information in pixel units was impossible.

4.2.1 Tricolor Vidicon

The first single-tube method with a built-in color filter was the tricolor Vidicon produced by RCA in 1955 (3). As shown in Fig. 4.2, the usual method involved separating the ITO (NESA coating) uniformly deposited on the transparent electrode into stripes and connecting every third one together to produce three output lines.

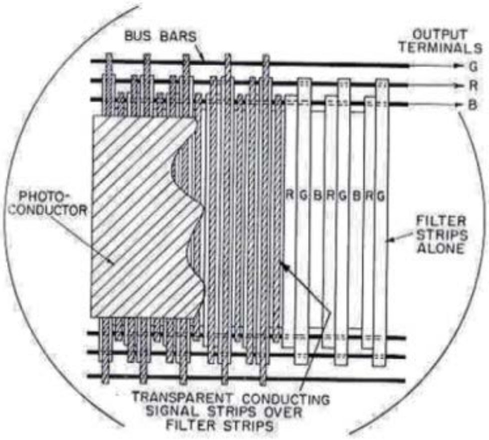


Fig. 4.2 Tricolor Vidicon (5)

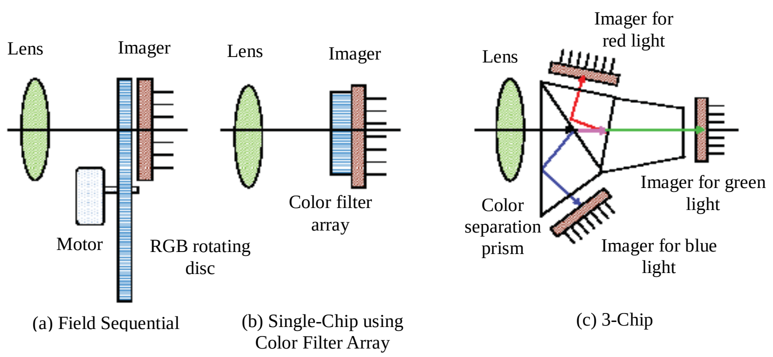


Fig.4.1 Color Image Pickup Methods (2)

Each of the three electrode groups had a striped RGB color filter, allowing separate RGB color signals to be obtained from the three output lines. In practice, this configuration results in color mixing by the effect of inter-wire capacitance, as well as a reduced S/N ratio. This capacitance can reach 300pF in one inch image pickup tube, with impedance reaching 400Ω at 1.3MHz. The load resistance must be reduced to avoid color mixing, which then reduces the S/N ratio. Some efforts to improve this have been published [4] [5].
Industrial cameras made by the RCA and Magnabox were commercialized using the tricolor Vidicon.

4.2.2 Frequency Multiplexing

In Nippon Columbia, research and development using this system has been actively carried out in the 1960s [6]. Since the manufacturer of the image pickup tube was limited at the time, research and development was carried out by using a normal Vidicon and a relay lens.
As shown in Fig. 4.3, the purpose of the relay lens is to re-focus the image from the stripe filter (then also called the strip filter) onto the photoconductive film in the image pickup tube. However, it must be re-imaged without degradation of the peripheral and resolution of peripheral light near image, there is unreasonable to optical design, the relay lens did not provide sufficient performance.

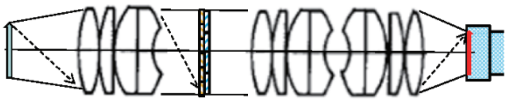
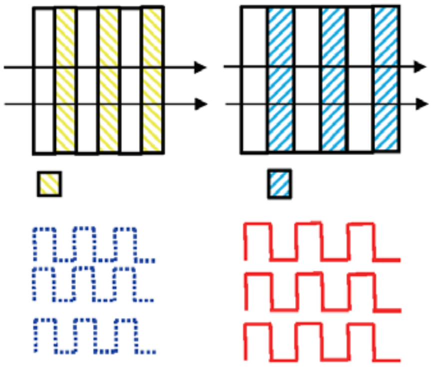
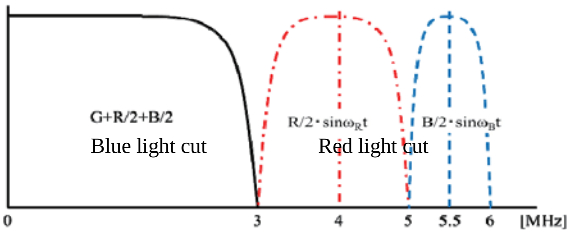


Fig. 4.3 Example of a Single-Tube Color Pickup System using Relay Lens

Principle diagram of a frequency multiplexing is shown in Fig. 4.4. As shown in Fig. (a), two types of stripe filters are used. A transparent filter and blue cut filter are arranged alternately in a stripe filters on the left. On the other hand, transparent and red cut filters are arranged alternately on the right. The optical image of the subject is amplitude modulated at a frequency corresponding to the pitch of each of these filters, producing the correlation between the modulated red signal and modulated blue signal shown in Fig. (b).
The resolution of this image pickup tube had to cover a wide frequency range of 6MHz, as shown in Fig. 4.4. This also required a special high-performance image pickup tube, as it required a high S/N ratio up to around 6MHz. Accordingly, it was difficult to consistently obtain an acceptable image.
Nippon Colombia continued its research and development of this method for a number of years and put it to practical use in industrial cameras [7]-[15].
Ideas on frequency multiplexing systems had long been proposed around the world. In 1953 Leslie H.



(a) Relation of Color Stripe Filter and Signal Waveform



(b) Relation of Each Color Siganal Frequency Bandwidth

Fig. 4.4 Frequency Multiplexing Color Pickup System

Bedford (Canadian Marconi) [16] [17] and Keith Teer (Phillips) [18] and in 1956 David Russell Tate (EMI) proposed indivisually single-tube color camera systems with two-color stripe filters [19]. These proposals came to public notice at 1958. These three inventions are respectively registered in the United States, the United Kingdom, Canada and Japan.
In contrast to these patents, initial proposal of Nippon Columbia in 1961 was limited to system having a mixer to remove beat interference [20]-[22].
Table 4.1 shows a list of these patents.

Table 4.1 Frequency Multiplexing System Patents

Item	Color Television Camera	Color Television Transmission	Color Television Transmission Filter	Improvement of an Apparatus for Simultaneously Generating Multiple Television Signals
Inventor	Ray D. Kell	Leslie H. Bedford	Leslie H. Bedford	Keith Teer
Maker	RCA	Canadian Marconi	Canadian Marconi	Philips
Appl. No.	301,503	650,962	659,355	
Filing date	July 29,1952	16-Jul-53	Jan. 6, 1954	Priority 1953-11-14
Publication No.				S33-3361
Publication date				1958/11/14
Patent No.	2,733,291	Canad 602,998	Canad 578,146	
Date of patent	Jan. 31, 1956	Aug. 9, 1960	June. 23, 1959	
Remarks	Basic patent for frequency multiplexing	Color camera having cyan and yellow stripe filters	Cyan and yellow stripe filters for color cameras	Color camera having cyan and yellow stripe filters

Item	Color Signal Generator	Color Signal Generating Apparatus Using a Single Camera Tube	Color Television Signal Generating Method	Composite Signal Generator
Inventor	David Russell Teat	Toshihiko Takagi, Shusaku Nagahara	Toshihiko Takagi, Shusaku Nagahara	Toshihiko Takagi, Shusaku Nagahara
Maker	EMI	Nippon Colombia	Nippon Colombia	Nippon colombia
Appl. No.		S36-18776	S37-31707	S38-70590
Filing date	Priority 1956-2-24	1961/5/27	1962/7/26	1963/12/26
Public notice No.	S35-14656	S39-13833	S40-5170	S42-12473
Public notice date	1960/10/5	1964/7/16	1965/3/18	1967/7/14
Patent No.				
Date of patent				
Remarks	Color camera having stripe filters	Single-tube color camera with a mixer for beat interference removal	A method of frequency multiplexing to avoid beat interference by tilting one color filter	A method of frequency multiplexing by tilting one color filter and vertical scanning

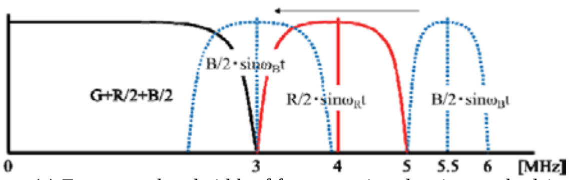
Corresponding British Patent 856,002

All three Nippon Colombia patents filed after the above four well-known examples

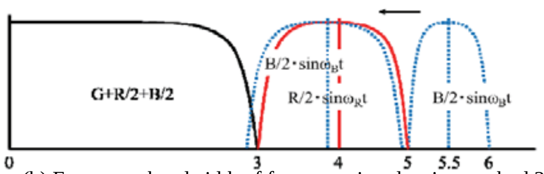
4.2.3 Frequency Interleaving

Frequency interleaving methods were presented by Hitachi and Toshiba both at the National Joint Convention of Four Electrical Engineering Related Associations in 1970. There were subtle differences between the presentations by the two companies.

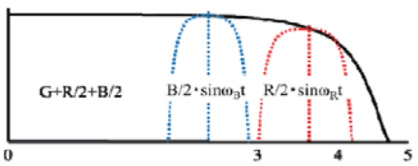
The Toshiba method [23] had the modulated B signal interleaved between the luminance signal and the modulated R signal, as shown in Fig. 4.5 (a) (b). The Hitachi method [24] had the modulated R and B signals interleaved into the luminance signal, as shown in Fig. 4.5 (c).



(a) Frequency bandwidth of frequency interleaving method 1



(b) Frequency bandwidth of frequency interleaving method 2



(c) Frequency bandwidth of frequency interleaving method 3

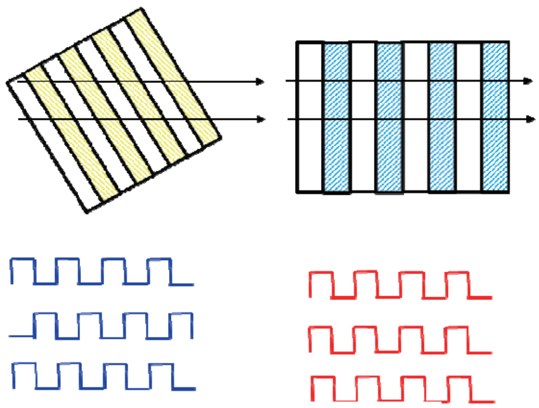

(d) Relation of Color stripe filter and signal waveform

Fig. 4.5 Frequency Interleaving Color Pickup System

Table 4.2 Frequency Interleaving Method Patents

Item	Color TV Camera Using Frequency Separation Single Camera Tube	Color Signal Generating Apparatus	Color TV Imaging Device	Color TV Imaging Device
Inventor	Haruo Sakata	Yoshizumi Eto	Yasuo Takemura	Motoi Yagi, Yasuo Takemura
Manufacturer	NHK	Hitachi	Toshiba	Toshiba
Appl. No.	S41-30805	S44-25544	S44-68387	S44-77051
Filing date	1966/5/16	1969/ 4/4	1969/8/30	1969/9/29
Publication No.				
Publication date				
Public notice No.	S45-8699	S49-49247	S50-34375	S51-32053
Public notice date	1970/3/28	1974/12/26	1975/11/7	1976/9/10
Patent No.	583954	787522	822621	857019
Date of patent	1970/9/22	1975/9/16	1976/7/28	1977/4/28
Content	Basic method interleaving single-carrier frequencies	Interleaving two modulated color signals in the luminance signal using two types of diagonal color filters	Crossing the arrays of two color stripe filters and arranging two types of carriers into an interleaving relationship	Interleaving two modulated color signals in the luminance signal using two types of tilted diagonal color filters

Item	Video System for Transmitting Two Independent Images	Color Signal Generator	Color Coding Camera	Imaging Device for Obtaining Multiple Signals
Inventor	Sue Yang Shy et al.	Jai Jerome Blanc Staudinger et al.	Robert Adams Dischart	Motoi Yagi, Yasuo Takemura
Manufacturer	Western Electric	RCA	RCA	Toshiba
Appl. No.	S46-3742	S46-6126	S46-6127	S45-11436
Filing date	Priority 1970/2/2	Priority 1970/2/11	Priority 1970/2/11	1970.2.12
Publication No.	S46-759	S46-1208	S46-1207	
Publication date	1971/9/3	1971/9/16	1971.9.16	
Public notice No.		S52-1615	S57-22503	S51-22775
Public notice date		1977/1/17	1982/5/13	1976.7.12
Patent No.			1142424	967285
Date of patent			1983.4.13	1979.7.26
Trial number	S51-7515	S51-7515	S51-7516	
Trial registration			1982.10.25	
Trial rejected		1981.9.30		
Abandoned	1978/12/14			
Content	The first tilting alternating color filter	Single carrier interleaved	Single carrier 120° interleaved	Single carrier interleaved
Remarks	Abandon	Refused due to objection from Panasonic (1976.4.6). Claim dismissed at trial (patent not satisfied) due to being the same as JPA 46-3742.	Refused (1976.4.6) Patent registered following appeal trial	Claims corrected (1979.10.8)

While conventional frequency multiplexing systems required the image pickup tube with a frequency bandwidth of up to 6MHz, as shown in Fig. 4.4 (b), these methods were both innovative method in that they were capable of achieving the same resolution with a bandwidth of 5MHz, thereby significantly narrowing the frequency bandwidth.

Toshiba then succeeded in achieving mass production of the Chromicon tube, in which the color filter was built inside the image pickup tube. This led to the commercialization of the world's first home video camera in 1974 [(25)]. While Hitachi also worked on camera development [(26) (27)], it focused on developing of frequency multiplexing systems [(28)-(36)].

As shown in Fig. (d), the frequency interleaving system involves positioning at least one of the color filters obliquely to the scanning direction, so that the phase of the modulated color signal alters by π for each scanning line. Thus it is possible to separate the two signals from a shared frequency. This method of frequency interleaving signals was presented and discussed in the Proc. IEEE in 1971 [(37)]. Detailed analysis results were reported after that [(38)-(42)].

Starting with Japan, there has been a number of proposals about this frequency interleaving method at the same time also from overseas manufacturers. These proposals are collectively shown in Table 4.2. The oldest is a single-carrier system proposed [(43) (44)] and the patent were registered by Sakata (NHK) in 1966. In 1969, Eto (Hitachi) applied for the patent [(45)] of the method 3 shown in Fig.4.5(c) and Takemura (Toshiba) also applied for the two patents [(46) (47)] of the method 2 and 3 shown in Fig.4.5 (a) and (b).

Overseas manufacturers to apply for patents included Sue Yang Shy et al. (Western Electric) [(49)] and Guy Jerome Brandingar et al. (RCA) in 1970 [(50)]. Both proposed frequency interleaving methods and applied for a priority claim in Japan, but both were deemed to be the same as the above-mentioned patents and were refused with no patent granted. One patent application filed in 1970 by Robert Adams Dischart (RCA) was granted with a limited priority claim [(51)].

Another patent for a single-carrier frequency interleaving method was applied for one day after the above-mentioned patent [(48)] and was granted with limitations.

The above conference presentations on frequency interleaving and the public release of the Sakata patent both took place in March 1970. All of the above patent proposals were filed until February 1970, which means they were all co-pending and unknown to each other. It is an interesting phenomenon that the similar idea was invented at the same time in different places around the world.

Next, let me show how the invention of the frequency interleaving was born. There were various opportunities for ideas to arise. In 1969, members of the Toshiba R&D Center were busy in the development and trial production of color TV phone exhibited in Osaka Expo.

Delivery time is approaching at hand, the project team had to struggle until midnight every night. Camera to be used in this set is a two-tube method, but the product of home video camera should be carried in single-tube method. However, no pickup tube that can be taken out stably frequency band of 6MHz. This is the mission of the Research Center to overcome the weaknesses. Moreover, there is no meaning unless a system in which other people do not have thought. This was not far from the head even while we are chased by a prototype. One night, after going to the bed and dozing off, Fourier analysis has been remembered that learned at student days. If the frequency could be interleaved, the bandwidth could be narrowed, allowing multiple color signals to be individually separated out. If this could be applied to single-tube method, it would be an effective use of frequency bandwidth. This method is possible by placing the color stripe filter diagonally to tha scanning direction.

It is not true that new ideas will not be born when you are busy with work because you have no time to think. Good ideas are often born when you are busy, because the energy has been enhanced.

4.2.4 Phase Separation Method (Trinicon Tube)

In contrast to the tricolor method of directly retrieving the RGB signals with three electrodes, the Trinicon method uses two electrodes, as shown in Fig. 4.6. Moreover, simply by retrieving the reference signal necessary for phase separation, it only needed one electrode to retrieve the RGB signal [(52)]. This made it possible to avoid the influence of the capacitance, which was a drawback with the tricolor system. It was possible to achieve phase separation using the index signal as a reference, as the color signal was an RGB sequential signal.

Using this method, professional cameras were commercialized from Sony in 1971.

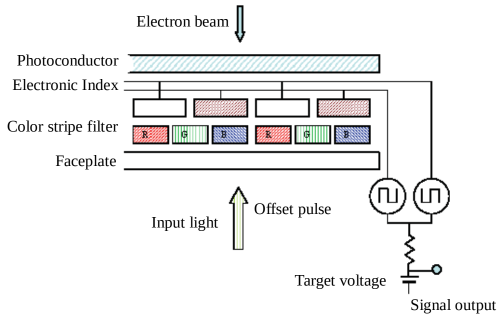


Fig. 4.6 Schematic Cross-Sectional View of a Trinicon

4.2.5 Step Energy Method

This method has a WCG stripe filter and is intended to separate two sets of color signals from the high-frequency component using envelope detection [(53)]. As shown in Fig. 4.7, a relatively wide-bandwidth luminance signal is separated out by LPF. Next, one of the color signals is separated by a narrow-band LPF. After the high-frequency component is separated out with a HPF and the 2R+B and R+2B color signals are separated by the two envelope detectors. Finally, the three RGB color signals are separated using a matrix circuit.

This scheme was proposed in 1978 by JVC and the single tube color camera was made using this method.

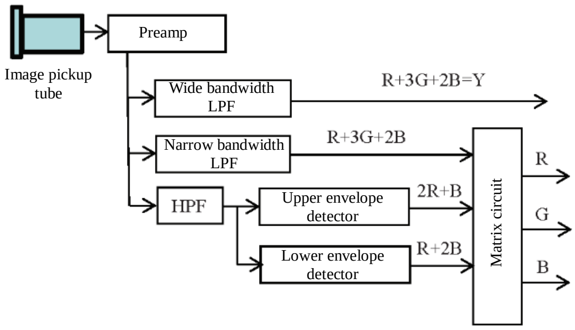


Fig. 4.7 Color Separate Circuits of Step Energy Color Pickup System

4.2.6 Three-Electrode Method
In 1974, three-electrode single tube color camera were developed from the Hitachi (54)-(57).

4.3 Two Tube Color Camera
High-performance Vidicon tubes were required for frequency multiplexing, as this incurred a high load on the tube. Accordingly, a two-tube color camera was developed, with one tube for the luminance signal and the other for the RB color signals (58) (59).
Fig. 4.8 shows a two-tube color camera optical system used in a color TV television phone (60) exhibited at the Osaka Expo in 1970.

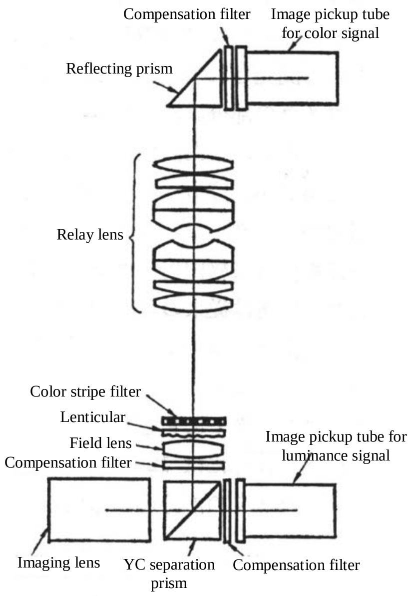


Fig. 4.8 Optical Aparatus of TwoTube Color TV Telephone

Here the carrier frequency of the blue signal is set to 1.4MHz. As frequency bandwidth of the color signal is 0.5MHz, a 2.5MHz frequency bandwidth is sufficient for the image pickup tube. A configuration of eight relay lenses was used in order to prevent any decrease in peripheral resolution and brightness.
It should be noted that this two-tube camera has been commercialized for business use as the IK-83 (62)-(64).
At the time, it gained attention as the business-use camera to sell for under ¥1 million.
In addition, as the broadcast camera, two-tube camera using an image orthicon was used by the NHK for the 1964 Tokyo Olympics (65) (66).

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5. Color Television Pickup System - Part 2 CCD/CMOS Imager Era

The image pickup tube obtains a signal by scanning a photosensitive surface with an electrode beam. Since the scanning would vary with the voltage applied to the deflection coil, the position of the pixels on the photosensitive surface could not be determined accurately. On the other hand, the photosensitive surface in CCD and CMOS image sensors is composed of a photodiode array, which means that the position of the pixels can be determined accurately in microns order. Since scanning is also performed by electronic switching, the pixel position, it is possible to specify the exact position of the pixel. This led to a new color imaging system different from that provided by the image pickup tube.
Table 1 shows the major color imaging systems.

Table 5.1 Major Color Imaging Systems

Year	Item
1960	Color separation prism that would become the basis for the 3-chip method [20]
1976	Bayer method [7]
1977	Horizontal pixel shifting 2-chip method [18]
1978	Improvement to the Bayer method [19]
1979	RB stripe 2-chip method [17]
1979	Pixel shifting 3-chip method [1]
1979	MOS-type W G Cy Ye method [14]
1980	MOS-type W G Cy Ye pixel shifting method [15] [16]
1982	Frequency interleaving method [10]
1982	Image shift [3]
1983	Field integration frequency interleaving method [11]-[13]
1983	Swing CCD [2]
1983	Frame integration color difference line sequential method [6]
1983	Field integration color difference line sequential method [5]
1984	Improvement to the Bayer method [8]
1984	Bayer system signal processing method [9]
1999	Vertical color separation sensor [24]
2007	WRGB method [21]-[23]

5.1 Bayer Method

As shown in Fig. 5.1, Bayer method of the basis of single-chip color filter is arranged in a checker board on the Y corresponding to the luminance signal, and aligning to the two color signals, C_1, C_2. Basic patent has been proposed by Bayer of Kodak in 1976 [1]. In practice, as shown in Fig. 5.2 (a), the green, which contain a large amount of the luminance signal, are arranged in a checkerboard pattern, and the red and blue are arranged in the remaining squares. As shown in Fig. 5.2 (b)-(d), among all the 16 pixels, G occupies eight pixels, and B and R occupies the 4 pixels. This layout is both horizontally and vertically symmetrical and is an acceptable, straightforward method for dealing with two-dimensional information.
However, standard television systems use interlaced scanning. If the Bayer method is used in interlacing, the red and blue images may appear alternately in each screen. One field memory is required to convert these to a simultaneous images. When you take a picture in motion, drawback occurs that movement becomes unnatural in the R, B images. Accordingly, this method was awkward to use in video cameras, which deal with moving images. Such arrangement has been extensively studied in the 1930's when it was about to colorization by using black and white film. In Japan, the patent proposal described above did not become registered [2].
There are various methods to separate the color signals from the CFA of the Bayer array [3]-[5]. These are described in chapter 9 below.

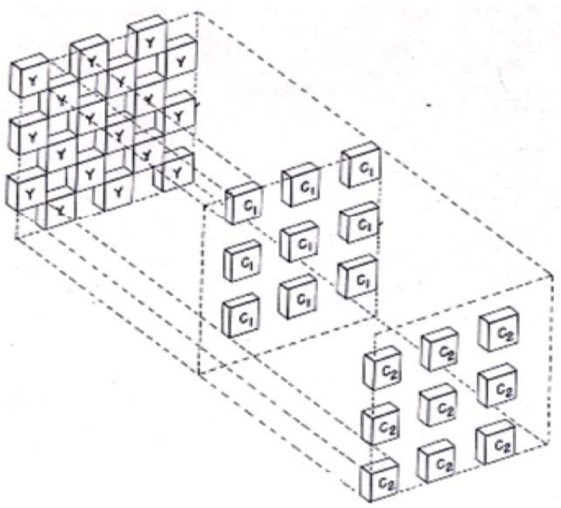
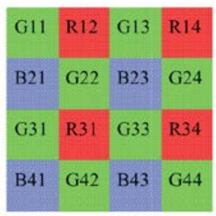
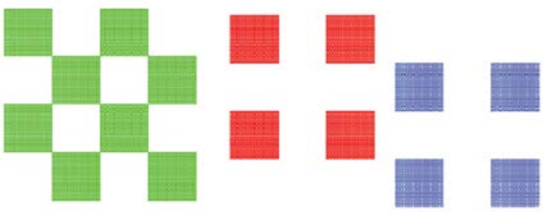


Fig. 5.1 Bayer Patent [1]



(a) In the case of 4x4 pixels

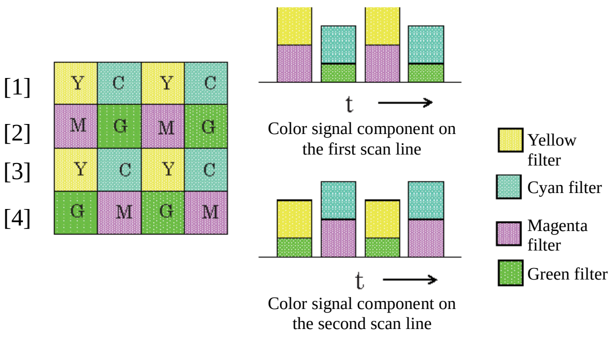


(b) G-pixels (c) R-pixels (d) B-pixels

Fig. 5.2 Bayer CFA - Primary Color Filter

5.2 Color-Difference Line-Sequential Method

The color-difference line-sequential method proposed by Morimura et al. (Matsushita) was a color array effective for moving images and suitable for addition readout [6] [7]. As shown in Fig. 5.3 (a), this CFA consists of four colors, one primary color G and three complementary colors Y, C and M. It is characterized that the order of G M in the fourth line is interchanged with the order of M G in the second line.



(a) Color Filter Array (b) Two-row addition readout signal

Fig. 5.3 Color-difference Line-sequential Color Filter

When reading the CFA in the first field, the signals are read by adding the signal of the first line (1) and the second line (2), and then are read by adding the signal of the third line (3) and the fourth line (4) and then the process is repeated below. For interlacing, adding combinations are changed in the next field. In the second field, the signals are read by adding the signal of the second line (2) and the third line (3), and then are read by adding the signal of the fourth line (4) and the fifth line (5) and then the process is repeated.
In this way, it is possible to obtain the output signals as shown in Fig. 5.3 (b). Here, the signal of Fig. 5.3 (b) can be expressed as the three primary color signals of Fig. 5.4 (b).
This color separation method can be explained using the following equations.
Since these waveforms are pulse amplitude modulation signals, they can be represented as a DC component and a fundamental wave component, by deploying in a Fourier series. In the first scanning line (odd-numbered scanning lines),

$$S_0 = (2R + 3G + 2B)/2 + \frac{1}{2}(2R - G)\sin 2\pi f_s t$$

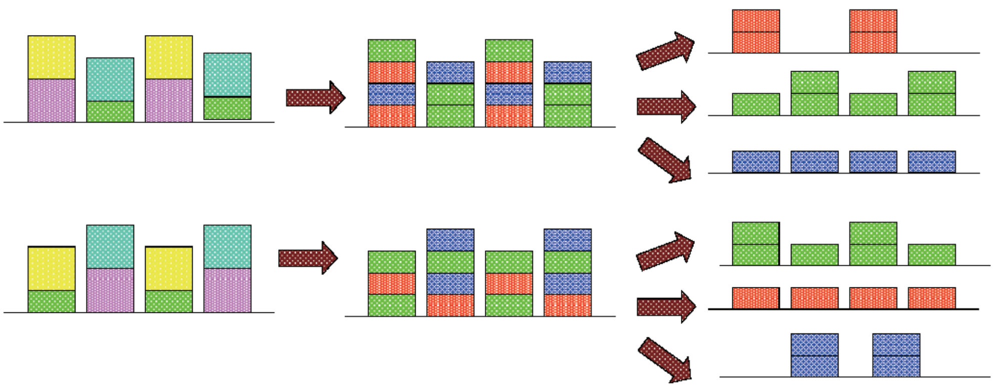
On the other hand, in the second scanning line (even-numbered scanning lines),

$$S_e = (2R + 3G + 2B)/2 + \frac{1}{2}(2B - G)\sin 2\pi f_s t$$

Here, f_s is the fundamental frequency determined by the pitch of the color filters.
As shown in the above equations, the luminance signal of the DC component is separated by the LPF. The two color-difference signals, (2R-G) and (2B-G) are obtained by separating the high-frequency component using the BPF centered at f_s. They can be obtained line-sequentially for each scanning line. Although the DC component and color-difference signals shown here differ slightly from the exact luminance signal and color-difference signals, they can be corrected using a matrix circuit.

5.3 Other Methods

Although various methods have been proposed, CFA method put to practical use in a video camera has been almost unified in line sequential complementary color difference and Bayer type primary color in currently. These methods are briefly touched upon below.



(a) Two-row addition readout signal (b) Primary color signal component (c) Three primary color signal components

Fig. 5.4 Color Separation using a Color-Difference Line-Sequential Method

5.3.1 WRGB Method

As shown in Fig. 5.5, WRGB method is obtained by replacing the one of Gs which is arranged two sequences in the Bayer method, to transparent W.

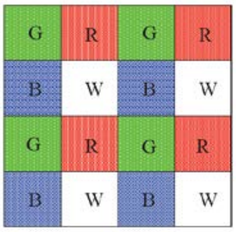


Fig. 5.5 WRGB Color Filter Array

Since the incident light in the W pixel area is not blocked by the color filter and is directly photoelectrically converted by the photodiode, this method can be expected to improve sensitivity. Image sensors using this filter array have been released successively by Toshiba [(8)-(10)] and Kodak [(11)].

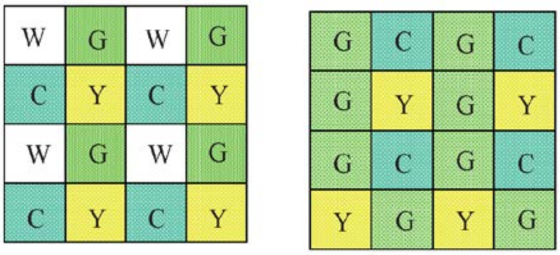
5.3.2 MOS Type Method

There were many suggestions of the image pickup methods to proceed in the development of Hitachi camera to focus on the MOS image sensors [(12)-(14)]. Since plurality signal outputs can be easily obtained, unlike the CCD, color signal multiplexing system was proposed utilizing its features. The MOS CFAs are shown in Fig. 5.6. The CFA shown in Fig. 5.6 (a) using four colors WCGY was called an orthogonal array, as it retrieved four respective output signals directly from the device. Since it could read out two lines simultaneously, it was possible to read out WG and YC simultaneously. Since signals of all pixels are read out in one field by this method, the so-called field readout has been able to achieve.

Meanwhile, Fig. (b) shows a Δ-symmetrical arrangement of color filters over the pixels, positioned to be 180˚ out of phase with the adjacent line. By pixel shifting effect, improvement of the resolution is performed.

5.3.3 Frequency Interleaving Method

This method was invented to adapt the same pixel arrangement used in camera tubes to CFA and to obtain red and blue signals in a frequency interleaving relationship. Toshiba proposed two readout types, frame readout and field readout, and commercialized these in some products [(15)-(18)].



(a) Frame readout (b) Field readout

Fig. 5.7 Frequency Interleaving

This method uses a color filter array repeated as a basic unit of 4x2 pixels as shown in Fig. 5.7. Both frame readout and field readout are possible. Fig. (a) shows the frame readout consisting of four colors W, G, C and Y, while Fig. (b) shows the field readout consisting of three colors C, G, and Y.

Using Fig. 5.7 (a), the principle of operation can be explained as follows.

The frame readout shown in Fig. (a) repeats the signal W, G, W, G… on the odd lines and C, Y, C, Y… on the even lines.

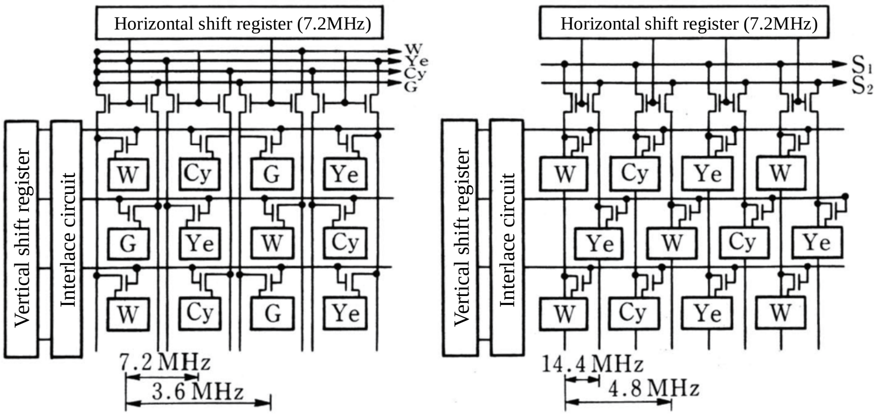
Since the signals are shown in

$W = R + G + B$

$Y = R + G$

$C = G + B$

the signals for each scan line are obtained as R, B signals by pulse-amplitude modulation, as shown in Fig. 5.8 (a) (i) and (ii).



(a) Orthogonal Array (b) Δ Array

Fig. 5.6 Example of MOS type-CFA

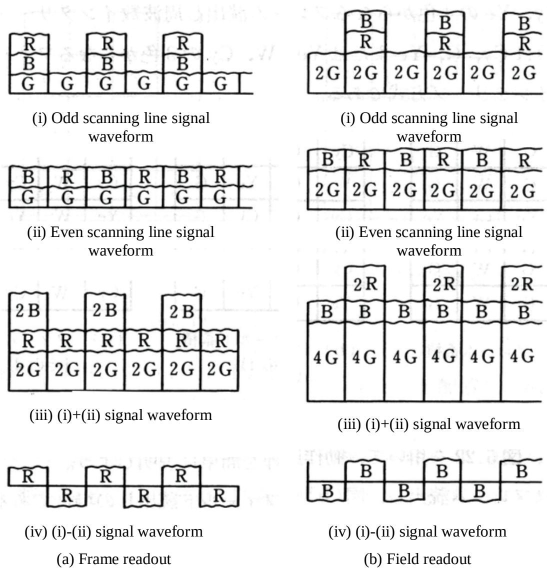


Fig. 5.8 Frequency Interleaving Signal Waveform

Thus, by addition of the signals of even lines and odd lines, R + 2G signal is obtained by the base band signal and 2B signal is the modulated signal, as shown in Fig. (iii). On the other hand, it is possible by subtraction to obtain the R signal modulated as shown in Fig. (iv). When analyzing the frequency components of these signals, the signals of the odd lines S_0 are represented by the following formula. Since the harmonic component of the pulse amplitude modulated signal falls outside the signal frequency band, we are focusing on the fundamental frequency component.

$$S_0=\frac{2G+C+Y}{2}+\frac{2G-2(C+Y)}{\pi}\sin 2\pi fs\,t$$

$$=\frac{R+4G+B}{2}-\frac{2\,(R+B)}{\pi}\sin 2\pi fs\,t$$

f_s: carrier frequency due to the CCD pixels

Similarly, signals of the even lines S_e are represented by the following formula.

$$S_e=\frac{G+Y+C+G}{2}+\frac{2(G+Y)-2(C+Y)}{\pi}\sin 2\pi fs\,t$$

$$=\frac{R+4G+B}{2}-\frac{2(R-B)}{\pi}\sin 2\pi fs\,t$$

The wide-bandwidth luminance signals E_y are represented equally in any scan line as

$$E_y=\frac{R+4G+B}{2}$$

On the other hand, if we represent the modulated color signal in the odd lines as E_{co} and in the even lines as E_{ce},

$$E_{co}=\frac{-2(R+B)}{\pi}\sin 2\pi fs\,t$$

$$E_{cy}=\frac{-2(R-B)}{\pi}\sin 2\pi fs\,t$$

Here, the carrier frequency of the modulated red signal has the same phase for each scanning line, while the carrier frequency of the modulated blue signal has the reverse phase for each scanning line.

Therefore, the carrier of the modulated color signals R, and B are different each other phase π, the two carrier signals are woven in frequency interleaving.

5.3.4 Vertical Color Separation Method

The methods described so far have been methods of obtaining separate color information for each pixel by arranging color filters in two dimensions. By contrast, vertical color-separation techniques are used to attempt to color separation within the thickness of one pixel. It must be made of a transparent material, including the wiring layer. Fig. 5.9 shows a conceptual diagram of this arrangement.

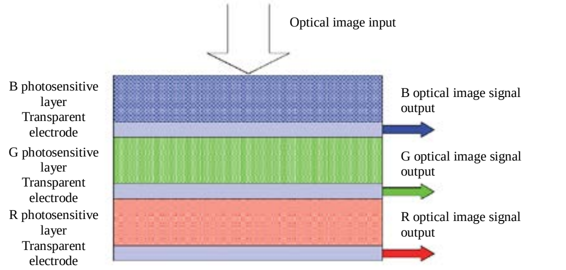


Fig. 5.9 Conceptual Diagram of Vertical Color Separation System

If it was possible to find a transparent material with a sharp wavelength selectivity to be able to separate the desired color and with full transparency to non-desired wavelength, it would be possible to produce the ideal image sensor.

Currently, the materials close to the above object are organic photoconductive film and Si semiconductor having wavelength selectivity. Observing the cross-section of the time when the light enters a photodiode, it is gradually absorbed as sequentially from the short wavelength blue to the long wavelength red and is photo-electrically converted. This means that if it was possible to extract the signal by separating the thickness direction, signals of different wavelengths could be obtained separately. Direct image sensor using this principle have been developed by Foveon, Inc., the digital camera is commercialized by Sigma Inc. [(19) - (21)].

On the other hand, by making a transparent photoelectric film using an organic material having wavelength selectivity, methods extracting signals decomposed three colors in the thickness direction, have been studied. Basic research and development has been promoted by NHK and Fujifilm each [(22)-(24)].

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6. Video Cameras

6.1 Overview

From the late 1960s, home use VCR has been started to spread. Then, not only for recording a television program, but also to be taken easily by themselves, video camera has been strongly desired.

However, it was a state in which the color program is not being broadcast only slightly in the television broadcast at that time. Color broadcast program has spread rapidly in the wake of the Osaka Expo. Research and development of a video camera aimed at the home use, has been intensified by each manufacturer. Home use color video camera was successful commercialization by Toshiba in 1974, and followed by other manufacturers successively commercializing single-tube video cameras using Vidicon [1][2].

Single-tube video camera went widely used as home use until CCD camera was commercialized in mid-1980. Because VCR for recording an output signal of the camera was initially stationary type, VCR must be moved on a cart. Moreover, coaxial video cable and audio cable were necessary to connect between the VCR and the camera. While portable VCR was eventually developed, for heavy still, it was used in the shoulder type. Nevertheless, there was a strong demand from consumers for cameras to record the activities of their children in school plays or on sports days. From the late 1970s, recording boom occurs, the number of video camera went rapidly increase[3].

However, it was so troublesome to connect cables between the camera and VCR and there was a strong demand to integrate the two. In part, a video camera integrated with the conventional VCR was commercialized. However, cassette size determined in the VHS system and β schemes which have become popular for home use was very large, so there were mechanical limitations to product miniaturization. To that end, progress was made on the development of a camera-specific VCR, VHS-C type and 8-mm method with a compact cassette appeared in 1985. Thereafter, the video camera will become a product that has been integrated with the VCR. Since this period was a time that each manufacturer has succeeded in mass production of CCD, production of the camera began to increase in quantity explosively during this period. While video cameras were first commercialized with 200k pixels, fierce pixels number competition has been started between each manufacturer in order to give the features. Pixel number competition of CCD was progressing from 300k pixels to 400k pixels, it was ended to meet the resolution of the NTSC system at 420k pixels. The 1990s saw the start of a new competition over performance. When it comes to the 1990s, high-performance competition begins. Accuracy of the AF and AWB is improved, and many new features were added, including image stabilization and face recognition. With the popularization of digital television in the 2000s, rapid progress was made in digital HDTV video cameras. Recording media also diversified to include not only DV and VCR formats, but also DVD, HDD and memory cards.

Meanwhile, as digital cameras for capturing still images increased in image sensor speed and memory capacity, they became capable of capturing moving images from around the late 2000s. Video cameras also became capable of taking still images; the boundary between the two was fading.

Let us now describe video camera production and the main video cameras in each period.

6.2 Video Camera Production

When the video camera statistics was started at 1983, production of the video camera was only 1.2 million units. This increased steadily each year and topped 10 million units in 1991, as shown in Table 6.1 and Fig. 6.1.

Table 6.1 Camera-Related Production [4]

	Video Camera	Digital Camera	Video Camera	Digital Camera
	Quantity (millions)	Quantity (millions)	Production (billion ¥)	Production (billion ¥)
1983	1.202		115	
1984	1.571		155	
1985	2.574		354	
1986	3.258		417	
1987	4.609		483	
1988	6.682		645	
1989	6.935		615	
1990	8.803		736	
1991	11.774		923	
1992	8.383		614	
1993	7.751		498	
1994	7.997		450	
1995	8.658		443	
1996	8.830		462	
1997	8.898		455	
1998	9.684		489	
1999	10.456	5.057	525	214
2000	11.706	9.615	549	327
2001	8.522	12.765	410	387
2002	8.993	16.916	415	436
2003	11.88	25.080	476	591
2004	11.957	29.200	418	736
2005	13.076	28.876	439	650
2006	12.524	37.150	392	731
2007	12.477	46.761	392	835
2008	7.928	36.273	246	706
2009	4.155	24.695	130	530
2020	3.856	24.206	132	435
2011	1.904	19.539	58	390

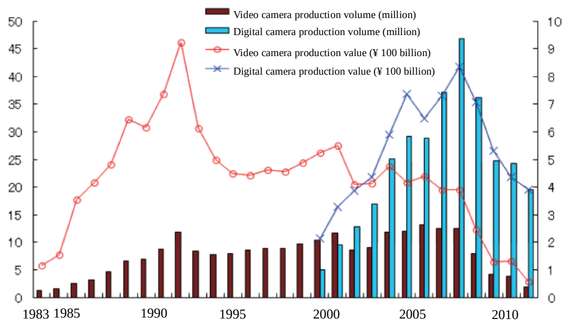

Fig. 6.1 Production of Video Cameras and Digital Cameras [4]

However, due to the impact of the economic downturn, decline was followed afterwards, although it increased again in 1995. Production output peaked again in 2000 and plateaued with the rapid rise of the digital camera. Since 2005, there has been a downward trend in quantity [4].

Meanwhile, in terms of price, production output peaked at ¥900 billion in 1991 and did not exceed this value with again. It was because the intensity of competition with mass production and cost reduction were continued.

Most of the video cameras had been exported. The number of domestic was 1.77 million units in 1988, and 2.08 million units in 1991. By the way, the penetration rate of the video camera in Japan was 29.9% against color TV 99.0% and 72.5% VCR in March 1994.

TV and VCR were transferred to overseas production from this time, domestic production went decreased. In contrast, the video camera domestic production has become one of the few electric appliances mainstream. It is worth noting that video camera production contributed to Japan's foreign currency income and also to securing employment in Japan.

In the chart, price and quantity of digital camera production are also shown for reference.

In production, it is a phenomenon of interest that digital camera growth of several years from 1999, is similar to the video camera growth of the number of years from 1983 statistics began. Price and quantity both peaked in 2007, followed by a downward phenomenon due to the intensification of price competition and the shift to overseas production thereafter. Since the camera function was incorporated into the cell phones and smartphones from the late 2000s, production of the video camera has decreased.

6.3 Single-Tube Video Camera

The filter integrated color (FIC) Vidicon was commercialized by Nippon Columbia in 1970 and single-tube color cameras for industrial use were commercialized [5]. In 1971, Sony also commercialized industrial use single-tube color camera using the phase separation method [6].

Under such circumstances, in 1974, home video camera of the world's first breakthrough was commercialized by Toshiba at ¥298,000 [7]. Toshiba succeeded in mass production of color cameras using the Chromicon camera tube. Until then, only a few cameras had been available for less than ¥1 million, with Toshiba's IK-83 two-tube color camera hitting the markets for ¥650,000.

Previous cameras had to be adjusted externally. A lot of volume to adjust the performance were installed in the camera, and when camera becomes worse, the performance has been repaired by adjusting them. Since the video camera is not necessarily the only professional use, they had to operate without any adjustments. As the result that design for compact, lightweight and robust was adopted, mass production became possible for the first time. A brochure of the world's first video camera IK-12 is shown in Fig. 6.2 [9].

Fig. 6.2 Brochure of the World's First Video Camera [9]

Before this camera was commercialized, Toshiba had in fact announced the development of a camera for home use [10]. This was two tube Vidicon camera about the same size as the 8mm film camera used for shooting the motion pictures that were popular at the time. This camera was exhibited at the IEEE Show held in New York and caught the great attention. However, the price was not appropriate for mass production for home use. The industrial use camera IK-83 was released in April 1972 at a price of ¥650,000, the cheapest at the time [11]. Since the optical system becomes complicated in 2-tube camera, it became necessary to develop a single-tube camera to produce low cost. Therefore, five years has elapsed before being commercialized as home use. Each manufacturer also began to establish a mass production technology of the camera in this opportunity. Sony which started from industrial cameras commercialized the home use phase separation method using Torinicon tube.

In addition, JVC has announced a single tube camera in step energy method to retrieve the color signal by the envelope detection can be divided into low-frequency and wide band frequency to the output signal in 1978. In addition, in 1979, Hitachi entered the home use camera using Saticon tube in tri-color method, and in 1980, Matsushita also entered using Newvicon single tube.

Notable among such movement is that almost all still camera manufacturers enhanced their conversion from film to electronic device. The reason for this is a sense of crisis that the film would disappear since the introduction of the electronic still camera of July 1981 from Sony. When it comes to 1982, Konishiroku, Canon and Nikon decided to launch of single tube video camera.

In this way, until the early 80's from the late 70's, single-tube video camera using an image pickup tube has become widespread, it went building the foundation of the video camera.

While CCD cameras began to be put to practical use in early 1980, they could not be spread since they were expensive and difficult to mass produce. However, as mass production technology was established in the mid-80s, video camera was replaced to the CCD camera rapidly.

6.4 Single Chip Color Camera

In April 1981, the world's first solid-state video camera, the VK-C1000 was released from Hitachi. Using a four-color CFA and a four-line MOS imaging device, the price of this camera was ¥350,000 [12]. Fig. 6.3 shows outline photography. Then, in October 1982, as shown in Fig. 6.4, the world's first CCD video camera the TC-100, was released from NEC at ¥278,000 [13]. This camera used Bayer-method IT-CCD. One year later, in October 1983, Sony released a Bayer-method IT-CCD video camera, the CCD-G5, at ¥228,000. At the same time, Hitachi released a new camera product with a two-line readout MOS imaging device using a two-color CFA at ¥218,000.

Fig. 6.3 The World's First Solid-State Video Camera using MOS Image Sensor (supplied by Hitachi)

Fig. 6.4 The World's First CCD Video Camera (supplied by NEC)

Price comparable to the single-tube camera by the advent of these cameras, has been gradually realized. In addition, CPD video camera was released at ¥258,000 from Panasonic using color difference line sequential method in October 1984. While CCD video camera using the same method was released from NEC at ¥198,000 in December the same year. Price of the video camera became under ¥200,000 for the first time.

Table 6.2 shows the single-chip video cameras brought out by different companies from 1984 to 1985 [3].

Table 6.2 Single-Chip Video Cameras Released in 1983-1984

Type	VK-C1500	VCK-100	CCD-G5	VZ-CD100	TC110	IK-3000
Manufacturer	Hitachi	Sanyo	Sony	Panasonic	NEC	Toshiba
Image sensor	MOS	MOS	CCD	CPD	CCD	CCD
Color pickup system	Pixel interpolation dot sequential	4-color simultaneous readout	Bayer	Color difference line-sequential	Color difference line-sequential	Frequency interleave
CFA	YCW chckered	GCYW	RGB chckered	YCMG chckered	YGC chckered	YGC chckered
Horizontal resolution (TV lines)	Over 300	250	250	250	250	250
Minimum illumination (lx)	35	28	30	30	9	20
Power consumption (W)	3.7	4.7	4.5	5	4	3
Imaging lens	6X Zoom	6X Zoom	6X Zoom	6X Zoom	6X Zoom	6X Zoom
(mm)	f=12.5-75	f=12.5-75	f=12-72	f=12.5-75	f=11--70	f=8.5-51
Dimensions W,H,D (mm)	124×134×195	149×139×192	107×137×218	209×168×242	120×148×183	108×137×223
Weight (kg)	0.98	1.09	1.02	0.98	0.98	0.95
Release date	Oct-83	Oct-83	Oct-83	Oct-84	Dec-84	-
Price (yen)	¥218,000	¥248,000	¥228,000	¥259,800	¥198,000	-

6.5 Video Camera Built-in VCR

While video cameras essentially required VCR the conventional Betamax and VHS formats could not be built into cameras due to the large cassette size. From the early 1980s, as there is a need to create a new VCR standard for video cameras, many manufacturers went to announce prototype video cameras built-in VCR by their own standards. As shown in Fig. 6.5(a), the Video Movie [14] in 1980, and the two months after it, as shown in Fig. 6.5 (b), Hitachi announced its Mag Camera [15]. Moreover, in the next 1981, Matsushita announced the Micro Video System [16] as shown in Fig. 6.5 (c). Sanyo also announced a camera-integrated ultra-compact VCR system in August 1981.

The gist of the 8mm video new format has been created, after preliminary draft of unified format has been discussed in the five companies. The five companies are JVC of VHS developer and Phillips (Netherlands) of V-2000 developer in addition to the above-mentioned three companies. Later, other manufacturers belonging the Electronic Industries Association of Japan, the Magnetic Tape Industry Association, the Japan Camera Industry Association and other related associations were invited to participate [17]. As a result, 8mm video conference is formed, and 8 mm video has been normalized by the approval of the 127 companies in April 1984 [18]. Refer to Chapter 7 for details.

As a result, from 1985 onwards, manufacturers produced so-called integrated VCR cameras with built-in VCR. Polaroid released an 8mm video camera using frequency-interleaving IT-CCD. In October 1984, 8mm video camera using a 250 000 pixel CCD was released at ¥298,000 from Sony. Following this ordinary 8mm camera, dedicated only recording camera was released at ¥198,000 in April 1985. Meanwhile, in October 1985, Matsushita released a VHS video camera using an 8mm size color-difference line-sequential IT-CCD at ¥298,000. Hitachi also released a VHS video camera with a new MOS-type sensor in February 1986, while Toshiba released a VHS video camera in April 1986.

(a) Video Movie (Sony)

(b) Mag Camera (Hitachi)

(c) Micro Video System (Panasonic)

Fig. 6.5 ProposedVCR-Integrated Video Cameras (from press releases by each company)

Table 6.3 Recording media built in camera in 1985-1986

Type	CCD V88AF	NV-M3	GR-C7	VM-500	VM-500
Manufacturer	Sony	Panasonic	JVC	Hitachi	Toshiba
VCR	8mm	VHS	VHS-C	VHS	VHS
Image sensor	2/3 CCD	8mm CCD	1/2 CCD	2/3 MOS	1/2 CCD
No. of pixels	250k	200k	220K	300K	200K
Color pickup system	G stripe	MGYC checkered	MGYC checkered	MGYC checkered	MGYC checkered
CFA	RB line-sequential	Color difference line-sequential	Color difference line-sequential	Separate 4-wire	Frequency interleave
Minimum illumination (lx)	19	10	15	10	10
Power consumption (W)	7.1	9.5	7.5	9.4	8
Imaging lens	6 times zoom	6 times zoom	6 times zoom	6 times zoom	6 times zoom
	F1.4 AF	F1.2 AF	F1.6 AF	F1.2 AF	F1.2 AF
Dimensions WHD (mm)	126×191×350	144×192×361	121×165×223	164×192×359	164×192×365
Weight (kg)	2.3	2.7	1.3	2.4	2.7
Release date	Oct-85	Oct-85	Feb-86	Feb-86	Apr-86
Price (Yen)	¥299,800	¥298,000	¥248,000	¥298,000	¥298,000

In addition, JVC launched a VHS-C format video camera in February 1986 to compete with the 8mm format, and 3 schemes were commercialized as the recording media. These video cameras are shown in Table 6.3 [3].

6.6 Increasing Pixel Numbers

As described so far, the most important factor for the video cameras of the 1970s and early 1980s was to achieve a resolution commensurate with NTSC broadcasting. It was also necessary to achieve a resolution comparable to that of the single-tube cameras that had gained early popularity. Accordingly, developers focused on implementing pixel numbers of 200k-250k. Once each manufacturer reached this level of resolution, as shown in Table 6.3, the goal then shifted to higher resolutions.
Since NTSC broadcasting has a 3.58MHz color subcarrier, 200k pixel image sensors were initially considered sufficient for a horizontal resolution of approximately 270 TV lines. However, by adoption of the new standard such as 8mm and S-VHS, horizontal resolution is improved to 400 TV lines more than the conventional VCR. This required an increase in the number of pixels of image sensor.
While the relationship between image sensor pixel size and resolution differs depending on the color image pickup system and luminance signal processing, the relationship between the horizontal resolution and number of pixels in a single-chip color camera is shown in Fig. 6.6 [19]. In the primary color systems, the G signal, which is the main component of the luminance signal, is relatively low. On the contrary, in complementary color systems, since G signal is contained in almost all pixels, there is the advantage in superior resolution.
As illustrated, in order to ensure the resolution of more than 400 TV lines, it was necessary to use an image sensor of 400,000 pixels. Since it was difficult to increase the pixel number at once from 200k to 400k, 400k has been achieved through a 300k.

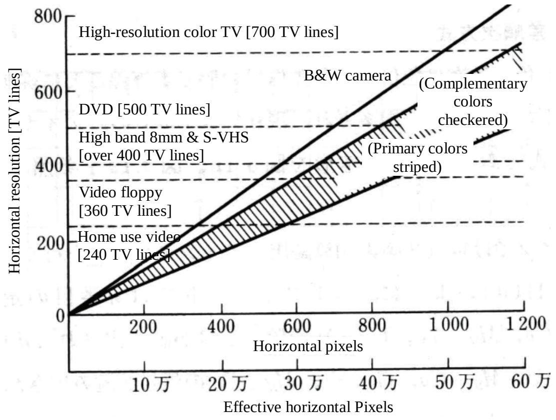

Fig. 6.6 Relationship between Horizontal Resolution and the Number of Image Sensor Pixels

Table 6.4 shows an example of changes in camera performance and specifications leading up to 400k pixels from 200k pixels. A 200k pixel sensor was capable of a horizontal resolution of 250 TV lines. This increased to 360 TV lines with the 300k pixel sensor. With a 420k pixel sensor, it was possible to achieve 470 TV lines and exceed S-VHS resolution.
In addition, high performance competition was also activated along with the image quality due to the pixels number, but this is discussed in Chapter 8.

6.7 Video Camera Trends

Many kinds of video cameras have been developed and commercialized. Let us note the progress from the point of view of some of these. Firstly, Table 6.5 shows the main video cameras from the 1970s to the present. For the sake of accurate as possible, this table has been created mainly by press releases and brochures by each manufacturer, in addition to conference presentations and bibliographies [3] [29] [30]. Therefore, please understand that numerical values set forth are not measured under the same conditions.

Table 6.4 Progress in Pixel Number and Examples of Camera Performance

	IK-3000	AI-30AF	AI-40SV	AI-XS1
Feature		High performance AWB	First 400k pixel camera	High resolution (first 420k pixel camera)
Imaging device	2/3 inch CCD	1/2 inch CCD	2/3 inch CCD	1/2 inch CCD
No. of pixels	200k	300k	400k	420k
Horizontal resolution	250 TV lines	360 TV lines	470 TV lines	470 TV lines
VCR	None	VHS-C	S-VHS	SVHS-C
Imaging lens	6 times zoom	6 times zoom	6 times zoom	8 times zoom
F number	1.2	1.2	1.7	1.2
Finder	0.6 inch B/W CRT	0.6 inch B/W CRT	0.6 inch B/W CRT	1 inch B/W CRT
Minimum illumination	50lx	8lx	15lx	7lx
Weight	1.1kg	1.6kg	1.7kg	1.34kg
Dimensions (W×H×D)	95×120×210	115×156×270mm	115×156×291mm	112×145×295mm
Power consumption	5W	8.5W	9.0W	10.3W
Release date	Autumn 1981	Aug. 1987	April 1988	Sep. 1989
Price	¥350,000	¥198,000	¥248,000	¥198,000

Weight includes cassette and battery

Table 6.5 Video Camera History

Year	Month	Type	Manufacturer	Inches / Image Sensor	Weight	Power Consumption	Recording device	Price	Characteristics
1970			Nippon Columbia	1-inch FICVidicon			Separate		Industrial use, color filter built-in, frequency-multiplexed, single-tube
1971			Sony	1-inch Trinicon			Separate		Industrial use, phase-separated, single-tube
		IK81	Toshiba	1-inch 2-chip Vidicon			Separate	800,000	Industrial use, color filter built-in, two-tube
1972	4	IK83	Toshiba	2/3inch 2chip Vidicon			Separate	650,000	Low cost industrial use, color filter built-in, two-tube
1973			Akai Professional				Separate	450,000	Low cost industrial use
1974	4	IK12	Toshiba	1inch Special Vidicon (Chromicon)			Separate	298,000	The world's first video camera for consumer use
		VCC-300	Sanyo Electric	25mm Electrostatic convergence, electromagnetic deflection Vidicon	2.8kg	15	Separate		
1975	5	3chip Prototype	NHK-NEC	CCD			Separate		Japan's first prototype
1978	4	IK1300	Toshiba	1inch Special Vidicon (Chromicon)	2.6kg	31W	Separate	227,000	Reduced cost, production of 3,000/month
		VK-C600E	Hitachi	Vidicon			Separate	178,000	
		GC-3350F	JVC	Single Tube			Separate	251,800	Step energy pickup system
1979	7	GX-V3	JVC		1.4kg		Separate	138,000	The world's smallest and lightest video camera for consumer use, single-tube
		XC-350JA	Sharp	Three-electrode single-tube	3kg	12W	Separate		
		VK-C830	Hitachi	Saticon Single Tube			Separate		Tri-color pickup system, Saticon tube
1980	1	XC-1	Sony	2/3inch 120K pixel IT-CCD	1.3kg		Separate		Two-chip CCD, the world's first cockpit camera for ANA B747
	6	IK-2300	Toshiba	2/3inch Special Vidicon (Chromicon)	2.5kg	9W	Separate	199,000	Minimum illumination 50lx
	7	Video Movie	Sony	2/3ich FT-CCD	2kg	7W	System Proposed		Integrated 8mm tape, prototype exhibited at the Berlin show in September
	9	VK-C1000	Hitachi	2/3inch MOS	1.1kg	3.8W	Separate	350,000	The world's first solid-state video camera, exhibited at the Electronics Show, released in April 1981
	9	Mag Camera	Hitachi	2/3inch MOS	2.6kg		System Proposed		Integrated 1/4tape VCR, prototype exhibited at the Berlin show in September
	10	Prototype	Toshiba	2/3inch 200K pixel CCD			Separate		Prototype exhibited in the Electronics Show
			Panasonic	New Cosvicon Single tube			Separate		
1981	2	Micro Video System	Panasonic	1/2inch Cosvicon	2.1kg	5W	System Proposed		Integrated 7mm tape (new evaporated tape proposed)
	4	HVC-F1	Sony	MF Trinicon	2.7kg		Separate	220,000	High-resolution picture with 300TV-lines
	5	Micro Video System	Panasonic	2/3inch CPD	1.9kg	4.9W	Integrated		Micro-video system using CPD, exhibited at the USA Panasonic Show
	5	IK-3000	Toshiba	2/3inch 200Kpixel CD	1.1kg	5W	Separate	350,000	Development and release announced
	8	Mavica	Sony				Floppy disc		The world's first electronic still camera, released in 1986
		VK-C1500	Hitachi	MOS	980g		Separate		Weighs less than 1kg
		XC-2P	Sharp	Single Vidicon			Separate	99,800	Zone focus, Good Design Award
1982	10	KONICA color VC	Konica	Single Carrier 1/2-inch Saticon	690g		Separate		First Photokina exhibition for camera manufacturers
		TC-100	NEC	CCD			Separate		The world's first CCD video camera for consumer use
		VK-C3000	Hitachi	MOS			Separate	288,000	The world's first video camera using auto focus
		VC-100	Canon				Separate		Canon's first
		S-100	Nikon				Separate		Nikon's first
		KY-1900	JVC	3-Tube Saticon			Separate		
1983	3	IK-C400	Toshiba	1/2-inch Saticon	890g	2.9W	Separate	145,000	Lightest & lowest power consumption
	7	BMC-100	Sony	1/2-inch SMF Trinicon	2.48kg		β	269,000	β- movie, the world's first video camera integrated VCR, recording only
	10	CCD•G5	Sony	2/3-inch 190K Pixel IT-CCD	1kg		Separate	228,000	The world's first mass produced CCD
	10	XC-37	Sony	2/3-inch 190K Pixel IT-CCD	115g		Separate		The smallest & lightest black & white camera for industrial use
		VCC-520	Sanyo Electric	1/2-inch Saticon	2.2kg	5.8	Separate	198,000	Portable β-VCR video camera
1984		TORONE	Minolta				Separate		

		VM-200	Hitachi					299,000	Integrated VCR
		GR-C1	JVC	1/2-inch Highband Saticon	1.9kg	7.6W	VHS-C	288,000	Integrated VHS-C VCR
		VCK-100	Sanyo	Solid-state Image Sensor	1.09kg	4.7	Separate	248,000	Portable β-VCR video camera
1985	1	CCD-V8	Sony	250K Pixel CCD	1.97kg		8mm	280,000	The world's first 8mm video camera
	4	NV-M1	Panasonic	Single tube New Cosvicon	2.5kg		VHS		Integrated VCR
	10	VM-E1	Canon	1/2-inch Saticon	1.98kg	7.5W	8mm	298,000	Canon’s first integrated VCR, phase separation pickup system
	12	NV-M3	Panasonic						Color difference line-sequential imaging system
1986	2	GR-C7	JVC	1/2-inch CCD	1.3kg	7.5W	VHS	248,000	The world's smallest & lightest VHS Video Movie Camera
	8	VC-C20	Sharp	2/3-inch ＣＣＤ	2.4kg	9.5W	VHS	255,500	Using F1.2 & 8x lens, Good Design Award
	8	NV-M21	Panasonic						High speed electronic shutter 1/10,000s
	9	CCD-M8	Sony	250K PixelCCD	1 kg		8mm	198,000	Handycam
	9	IK-M10B	Toshiba	200K Pixel CCD	25g	4.2W	Separate	500,000	The world's smallest camera , 17.5φ & 53mm in length
	9	IK-C20A	Toshiba	200K Pixel CCD	100 g	4.3W	Separate	300,000	Box-type camera with changeable C-mount lens
	10	CCD-V30	Sony	250K PixelCCD	1 .4kg		8mm	198,000	Playback-capable Handycam
1987	6	NV-MS1	Panasonic	420K PixelCCD			S-VHS		S-VHS integrated
	8	AI-30F	Toshiba	1/2-inch 300K Pixel CCD	1.3kg	8.5W	VHS-C	198,000	300k pixels high image quality
	9	VL-C51	Sharp	CCD	1.2kg	7.5W	VHS-C	198,000	High speed electronic shutter 1/1,000s, 8x zoom lens
		NV-MC15	Panasonic						
		VEM-D1	Sanyo	1/2-inch 270K Pixel CCD	2.1kg	6.8	8mm	198,000	Integrated 8mm VCR
1988	6	IK-T30C	Toshiba	1/2-inch 300K Pixel 3-chip CCD	730g		Separate		The world's first compact 3-CCD camera, 72x71x156mm (W×H×D)
	6	VL-C65	Sharp	1/2-inch 270K Pixel CCD			VHS-C		8x zoom lens, ergonomic design
	8	IK-M30	Toshiba	1/2-inch 300K Pixel CCD	25g	4.2W	Separate		Compact camera, 300k pixels
	9	CCD-V88	Sony	2/3-inch 420K pixel CCD	0.9kg		8mmm	215,000	The smallest & lightest camera using TTL AF/AWB
	11	GR-A30	JVC				Integrated		Using Full range AF
		AI-35AF	Toshiba	1/2-inch 300K Pixel CCD	1.68 ㎏	8.5W	VHS-C	178,000	Flicker compensation
		AI-41SV	Toshiba	1/2-inch 400K Pixel CCD	1.4kg	9.0W	SVHS-C	218,000	High image quality 400k pixels
		VL-C650	Sharp				VHS-C		1.5inch color LCD finder, enlarged by lens
		PV-460	Panasonic						The first optical image stabilization camera for the US market
1989	9	AI-XS1	Toshiba	1/2-inch 420K Pixel CCD	1.34kg	10.3W	SVHS-C	198,000	Increased competition over pixel number; advent of NTSC 420k pixels
		CCD-TR55	Sony	1/2-inch CCD	790g		8mm	160,000	Passport size video camera with 6x zoom lens
		S-K3D7	Toshiba	1/2-inch 300K Pixel CCD	1.67kg		VHS-C		The world's first stereoscopic video camera
		A1	Canon	1/2-inch 360K Pixel CCD	1.5kg	8.3W	Hi8	260,000	Good Design Award
1990	4	GET'S	JVC				Integrated		S-VHS movie composition
	6	NV-S1	Panasonic	1/3-inch CCD			SVHS-C		Brenbee, image stabilization camera using fuzzy logic
	9	KY-90	JVC						3-CCD camera with IC card
		VM-ES88	Sanyo	1/2-inch 250K Pixel CCD	780g	6.5W	8mm	163,000	Jiema, binocular style
		BCC-100	Toshiba	1/2-inch 410K Pixel 3-chip CCD			Hi8		3CCD camera recorder for industrial use, development CCD bonding equipment
		SC-C01	JVC	1/2-inch 360K Pixel CCD			S-VHS-C		GET'S, necessary parts removable camera
		ES-30TW	FujiFilm	1/2-inch 400K Pixel CCD			Floppy disc		Electronic still camera
1991		LX-1	Canon				Hi8		VL mount camera (new lens mount system developed between Canon, Sony, Hitachi and Panasonic)
		VM-ES800	Sanyo	1/3-inch 270K Pixel CCD	690g	5.5W	8mm	158,000	Jiema, using fuzzy logic for AE, AF, AWF
1992	4	CCD-TR900	Sony	1/3-inch 410K Pixel CCD	860g		Hi8		1/3 smaller and lighter camera, 410k pixel precision CCD
	9	GR-SZ1	JVC				Integrated	-	Video movie camera supporting wide-angle, telescopic and microscopic shooting

	10	VL-HL1	Sharp	1/3-inch 410K Pixel CCD	890 g	9.4W	Hi-8	210,000	The world's first LCD monitor camera, LCD-View Cam
		NV-3CCD1	Panasonic	3 chip CCD			S-VHS-C	298,000	Brenbee Pro,
		CCD-VX1	Sony	410K Pixel 3-chip CCD	1.5kg		Hi-8	350,000	Flagship model of the consumer use video camera
		VL-HX1	Sharp	1/3-inch 410K Pixel CCD				198,000	Twin-cam 8, zoom lens & wide-angle
1993		FS-1	Fuji Film	1/3-inch 410K Pixel CCD			Hi8		Simple High-8
1994	2	THK-500D	Toshiba	2/3-inch 1.3M Pixel 3-chip CCD	900g		Separate		HDTV 3-CCD camera, 1000 TV lines resolution
	5	GR-EX7	JVC	CCD	815g	8W	Integrated	185,000	S-VHS stereoscopic Hifi movie
		E1	Canon	1/2-inch 410K Pixel CCD					Movie-Boy, visual line input in the viewfinder
1995	4	CCD-TRV90	Sony	1/3-inch CCD	1.1kg		Hi8		TRV style, opening and closing side LCD monitor
	9	NV-DJ1	Panasonic	3CCD			DV	275,000	Digicam, digital high resolution camera with 500 TV lines resolution
	9	DCR-VX1000	Sony	1/3-inch 410K Pixel 3chip CCD	1.4kg		DV	350,000	Digital Handycam using DV Standard
	9	DCR-VX700	Sony	Single chip CCD			DV	235,000	
	12	GR-DV1	JVC	1/3-inch 570K Pixel CCD	450g		DV	220,000	Pocket digital movie using DV Standard
	12	VL-DH5000	Sharp	1/4-inch 410K Pixel CCD	1.19kg	10.4W	miniDV		Digital recording with 224.64K pixel LCD monitor
		QV-10	Casio Computer						LCD digital camera, full-scale popularization begins
		VM-H39	Hitachi						No image degradation
1996	10	GR-DVM1	JVC	1/3-inch CCD	620g	8.7W	Integrated	230,000	Pocket Digital Movie, LCD video camera
		VM-PS102	Sanyo	1/4-inch 270K Pixel CCD	640g	3.9W	8mm	Open price	Standard AA battery-operated, 2 hours recording
1997	7	PK-MC202	NEC	320×240 pixel 1/4-inch CCD	200g		Separate		The world's first USB-compatible camera
	8	Allegretto PDR -2	Toshiba	1/4-inch 330K Pixel CMOS	130g			59,800	The world's first CMOS digital camera
	9	MV1	Canon	1/3-inch 380K Pixel Progressive CCD	930g	7.1W	miniDV	235,000	Progressive frame still image
	11	GR-DVL	JVC	380K Pixel CCD	670g	6.3W	Integrated		Progressive 500TV line resolution
1998	2	XL-1	Canon	1/3-inch 270K Pixel CCD	1.7kg	9.5W	miniDV	588,000	3-CCD lens exchangeable, XL lens mount, for top amateur / professional use
	9	DCR-TRV900	Sony	1/4-inch 3chip CCD	880g		DV		Interlaced / progressive switchable
		GR-DLS1	JVC	380K Pixel CCD	670g	6.3W	Integrated		Optical 10x, total 200x zoom
1999		D1	Nikon						Digital single-lens reflex camera compatible with existing SLRs
1999	9	ADA	Fuji Heavy Industries	CCD					Automotive stereo camera (with Legacy Lancaster), Active Driving Assist
2000	5	DCR-VX2000	Sony	1/3-inch 380K Pixel 3chip CCD	1.4kg		DV	380,000	Memory stick slot equipment
	7	VL-MR1	Sharp	1/4-inch 680K Pixel CCD	880g	5.0W	miniDV	230,000	First D terminal deployment, SD card compatible
		GR-DVA2000	JVC	1/4-inch 680K Pixel CCD	660g	4.4W	Integrated		Movie player, digital camera combined
2001	8	VL-NZ10	Sharp	1/4-inch 680K Pixel CCD	450g	4.4W	miniDV		LCD digital view cam, 3-inch LCD monitor
		IDC-1000Z	Sanyo	1/2-inch 1.5M Pixel CCD	575g		iD Disc	160,000	iDshot, world's smallest magneto-optical disc camera, first use of IEEE 1394
2002		X3	Foveon	3-color Stacked CMOS					Stacked single-lens reflex digital camera
2002	6	VL-MG10	Sharp	1/4-inch 1.33M Pixel CCD	590g	4.8W	miniDV		3-inch LCD camera with flash light
	8	VL-DD10	Sharp		630g	5W	miniDV		Video Camera Separation Type
		AG-DVX100	Panasonic				DV		Video camera capable of cinematography, 24p shooting and gamma mode
2003	2	VL-Z7	Sharp	1/4-inch 1.33M Pixel CCD	580g	4.4W	miniDV		2.5inch LCD monitor, SD card supported
		HD1	JVC	1/8-inch 4.2M Pixel CCD/1/4-inch 680K Pixel CCD					The first HDTV equivalent video camera
		DMX-C1	Sanyo	1/2.7-inch 3.34M Pixel CCD	155g	2.9W	SD Card	Open price	Xacti, the first MPEG-4 movie camera, VGA 30fps
2004	2	TK-WD310	JVC				Separate		WDR camera using Pixim image sensor
	10	HDR-FX1	Sony	1/3-inch 1.12M Pixel 3chip CCD	2.0kg		HDV	Open price	Home-use HDTV video camera with 1080i signal
2005	7	HDR-HC1	Sony	1/3-inch 2.97M Pixel CMOS	680g		HDV	Open price	Compact Home Use HDTV Camera using Primary Color Filter,
	9	MEHV10	Toshiba	5M Pixel CCD			HDD	Open price	The first video camera with 0.85inch HDD (4 GB), from tape to HDD
2006	7	HDR-UX1	Sony	1/3-inch CMOS	660g		DVD	Open price	Digital HDTV video camera using AVCHD standard
	7	HDR-SR1	Sony	1/3-inch CMOS	640g		HDD	Open price	Digital HDTV video camera using AVCHD standard
		DZ-GK3300	Hitachi				DVD	Open price	The first video camera with DVD
		DMX-HD1	Sanyo	1/2.5-inch 5.36M Pixel CCD	210g	4.3W	SD Card	Open price	The smallest & lightest HDTV video camera
		DMX-CA6	Sanyo	1/2.5-inch 6.37M Pixel CCD	155g	3.1W	SD Card	Open price	World’s first life waterproof video camera
		DMX-CA65	Sanyo	1/2.5-inch 6.37M Pixel CCD	220g	3.2W	SD Card	Open price	Waterproof video camera
2007	1	HDC-SD1	Panasonic				SD Card	Open price	AVCHD format

	9	GSC-A100F	Toshiba	1/3-inch 2.36M Pixel CMOS	495g		HDD	Open price	The smallest full HDTV video camera using 100GB HDD
		DMX-CG65	Sanyo	1/2.5-inch 6.18M Pixel CCD	150g	3.3W	SD Card	Open price	Video Camera using MPEG4 AVC (H.264) format
2008	9	D90	Nikon	23.6×15.8mm 12.9M Pixel CMOS				Open price	The world's first single-lens reflex camera capable take HDTV Moving Images
	11	EOS 5D Mark II	Canon	36×24mm 21.1M Pixel CMOS				Open price	The world's first single-lens reflex camera capable take full HDTV Moving Images
		HDR-FX1000	Sony	ClearVid CMOS			HDV	Open price	HDV professional flagship camera
		DMX-HD1000	Sanyo	1/2.5-inch 4M Pixel CMOS	270g	4.2W	SD Card	Open price	The world's smallest & lightest full HD movie camera
2009		DMX-HD2000	Sanyo	1/2.5-inch 8.1M Pixel CMOS	268g	4.3W	SD Card	Open price	The world's first progressive HD video camera, 1080 60P
		DMX-CG10	Sanyo	1/2.33-inch 10.66M Pixel CMOS	171g	2.7W	SD Card	Open price	Compact 10million-pixel camera
2010	1	HDR-AX2000	Sony	1/3-inch 3chip CMOS	2.1kg		Memory	Open price	HDV → AVCHD, from tape to memory
	9	NEX-VG10	Sony	APS-C Size CMOS	620g		Memory	Open price	Interchangeable lens HD video camera
2012	10	EOS-C300	Canon	35mm fullsize 18.1M Pixel CMOS	1.82kg	23.9W	Memory	Open price	4K cinema camera, 2012 Emmy Award
	10	EOS-C500	Canon	35mm fullsize 8.29M Pixel CMOS	1.43kg	11.7W	Memory	Open price	2K full HD video camera, 2012Emmy Award
	10	NEX-VG900	Sony	35mm fullsize 24.3M Pixel CMOS	1.03kg			328,000	Interchangeable 35mm lens full-size CMOS camera
	12	NEX-VG30	Sony	APS size 16.1M Pixel CMOS	1.42kg			178,000	
2013	2	X920M	Panasonic	1/2.3-inch backside-illuminated 3-CMOS	480g	5.9W			Having 12.76 million pixels

About the notation of the manufacturer's name, Matsushita, Sanyo wrote under the name of the time.

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Innovation of the video camera was intense, during the period from the emergence of the video camera in the late 1970s to the 1990s. Remarkable video cameras that represent the era are summarized in Table 6.6. Notable cameras include the single-tube IK-12, the world’s first home use video camera, the VK-C100, the world’s first solid-state imaging camera to be commercialized, and the TC-100, the world’s first video camera to have a CCD image sensor, which later became the main image sensor for video cameras for a lomg time. While there was some initial difficulty in mass producing CCD cameras, the CCD-G5 quickly succeeded in mass production. Most of these so far were dedicated imaging cameras with no means of recording captured images.

Fig. 6.7 Passport-Sized Video Camera (18)

Table 6.6 Specifications of Representative Video Cameras from Each Era (late 1970s to 1990s)

Item	Image Pickup Tube	MOS Type	CCD	CCD	8mm
	IK-12	VK-C1000	TC-100	CCD-G5	CCD-TR55
	Toshiba	Hitachi	NEC	Sony	Sony
Features	The world's first home-use video camera	The world's first solid-state video camera	The world's first CCD video camera	The world's first mass produced video camera	Passport size (popularization trigger product)
Image sensor	1inch Vidicon	2/3inch 190K Pixels MOS	IT-CCD	2/3inch 190K Pixels CCD	2/3inch 270K Pixels CCD
Color pickup system	Ye, Cy stripe Frequency Interleave	Cy, W, Ye, G Mosaic	R, G, B Checker Bayer	R, G, B Checker Bayer	Mg, G, Ye, Cy hecker Sequential color difference
Horizontal resolution	250TV lines	260TV lines		250TV lines	-
Imaging lens	Fixed (C-mount interchangeable)	6x zoom lens		6x zoom lens	6x zoom lens
Finder	-	Electronic View Finder		1inch B&W CRT	0.6inch B&W CRT
Electronic shutter	None	None		None	1/60-1/4000
Weight	2.6kg	1.7kg		1.02kg	0.79kg
Size (W×H×D)	90×170×345	58×100×155mm		107×137×218mm	107×106×176mm
Power consumption	65W	5.3W		4.5W	5.2W
Release date	April 1974	April 1981	Oct. 1982	Oct. 1983	June 1989
Price	¥298,000	¥350,000	¥278,000	¥228,000	¥160,000

Item	SVHS-C	SVHS-C	Hi8	DV (6mm Digital)	DV (6mm Digital)
	AI-XS1	NV-S1	VL-HL1	NV-DJ1	DCR-VX1000
	Toshiba	Panasonic	Sharp	Panasonic	Sony
Features	400K pixels CCD Video Camera	Image Stabilization	LCD Viewcam	Digital Recording	Digital Recording
Image sensor	1/2inch 380k pixels CCD	1/3inch 270k pixels CCD	380k CCD	1/4inch 270k pixels CCD	1/3inch 380k CCD
Color pickup system	Mg, G, Ye, Cy Checkered Sequential color difference	Mg, G, Ye, Cy Checker Sequential color difference	Mg, G, Ye, Cy Checker Sequential color difference	RGB 3-chip CCD	RGB 3-chip CCD
Horizontal Resolution	470 TV lines	330 TV lines	-	500 TV lines	500 TV lines
Imaging lens	8x zoom lens	6x zoom lens	-	10x zoom lens	10x zoom lens
Finder	1inch B&W CRT	-	4inch Color LCD	Color LCD	Color LCD
Electronic shutter	1/60-1/10,000	1/100-1/4,000	1/60-1/10,000	1/60-1/8000	1/4-1/10,000
Weight	1.3kg	0.97kg	0.89kg	1.1kg	1.6kg
Size (W×H×D)	112×145×295mm	96×134×167mm	198×144×78 mm	144×122×266.5 mm	110×144×329
Power consumption	10.3W	7.8W	9.3W	7.5W	9.5W
Release date	Sep. 1989	June 1990	Oct 1992	Sep.1995	Sep. 1995
Price	¥198,000	¥165,000	¥210,000	¥275,000	¥235,000

The Video camera CD-TR55, shown in Fig. 6.7, was the first video camera with integrated VCR having a recording function. Moreover, since this camera are summarized in passport size, by this model, video cameras could be spread in earnest. While the resolution of a video camera was insufficient still until here, AI-X1 was the first successful camera using the 420k pixels CCD, and with the advent of this camera, increased competition of the pixels number of CCD was put an end. In terms of function, the video camera NV-S1 with auto stabilization function first solved the hand shake plagued until it. Auto Stabilization (AS) has become indispensable in addition to the three major functions AE, AF, AWB of this later. In 1995, the DV-format camera appeared, enabling digital recording with no loss of image quality. When people wanted to edit the captured image, degradation of image quality could not be avoided at the time of dubbing by analog recording up to it. But, the trouble has been resolved after the digital recording.

6.8 Video Camera Progress

Here, with reference to Fig. 6.8, let us trace the evolution of the video camera by era.
As shown in Fig. 6.8 (a), because it was quite heavy at the time when first video camera was announced in 1969, it was the type to put on a tripod yet. The shoulder type video camera put on the shoulder in 1974 has been put into practical use. Fig. 6.8 (d) shows the final single-tube video camera, which has achieved a considerable degree of miniaturization. However, it still has a separate VCR for recording, which has to be put on the shoulder. By the late 1980s, 8mm VCR and VHS-C appeared and cameras could be supported in the palm of the hand. While cameras remained in this format for a while, by the advent of recording media replaced to SD card, HDD, or DVD further from the VCR, miniaturization has become possible to fit in the palm of the hand, as shown in Fig. 6.8 (f).

6.9 Application of Video Camera Technology

Following the invention of the CCD in 1970, manufacturers around the world continued their research and development on video cameras. In order to achieve the performance that surpasses the pickup tube, intense development competition ensued among Japanese manufacturers aiming video camera in particular. As a result, from the early 1980s, manufacturers issued many press releases on video camera development and commercialization. In many cases, commercialization was postponed about six months due to delays in establishing mass production technology.
Manufacturers struggling to mass produce CCDs turned their efforts to producing professional cameras on a relatively smaller production scale.
Sony commercialized the first box-type professional camera in September 1983. In 1988, Toshiba commercialized the world's first 3CCD camera, the IK-T30C. New high-precision bonding equipment developed for this could bond three color-separation prisms accurately to the photosensitive surface of the CCDs.

6.9.1 Thumb-Size Camera (Ultra-Compact Camera)

An ultra-compact, thumb-sized camera was commercialized by Toshiba in September 1986, as shown in Fig. 6.9 [(20)-(22)]. This made it possible to shoot from camera angles that could not be captured with existing cameras. In the Lake Biwa Marathon, by mounting the camera to an escort motorcycle, it captured vividly the movement of the legs of the runners. These images were broadcast by the NHK, and seeing this image, commentators raised the voice of surprise. Mounting a camera to the helmet of a test skier on a downhill ski course on Mt Furano, this camera made it possible to deliver dynamic, real images in the skier's view of the up

Fig. 6.9 The World's First Ultra-Miniature Camera

(a) Two-tube prototype 1969

(b) Single-tube IK12 1974

(c) Single-tube IK3000 1981

(d) Single-tube IKC400 1983

(e) VHS-C integrated AI35AF 1988

(f) HDD integrated 2005

Fig.6.8 External View of Changes in Video Cameras

and down course directly into people's living rooms. The NHK broadcast these images for the first time in the world, drawing rave reviews. In addition, it was also being used to the scene put quietly next to the glasses in "A Taxing Woman" movie.
The idea of this innovative camera came from a short story by Yasushi Inoue, *The Eyes of Others.*
Despite CCD has become smaller, why are remain video cameras so big? In addition, we cannot put the camera to the place anywhere we want to see.
This was the ultimate dream for camera researchers. What would happen if you move the eye out of the camera? It was very difficult to implement such a trivial idea. This exploring of the unknown went on under the table (internally-funded development), while conventional business went on as usual. There were no experts in this new field of research. Even if a prototype could somehow be made, if it were too novel idea, it was difficult to get people of the manufacturing site to recognize the benefits of it. Before the prototype was discarded, the micro-camera was put to users to test out and was very well-received. The ultimate dream and the change in thinking resulted in the realization of the world's first micro-camera.

6.9.2 Electronic Endoscope

The practical electronic endoscope, so commonplace today, was developed in Japan in 1987 [(23)-(25)]. Before that, doctors observed the fiber scope image consisting of 50k elements and took photographs as necessary. When the CCD could be directly attached to the tip of the scope, more doctors at the same time could observe a television screen, as shown in Fig. 6.10. The number of doctors experiencing lower back pain is said to have decreased due to no longer having to stand in an unnatural posture necessary to operate the endoscope. The endoscope has now advanced from being an observation tool to a surgical tool, having forceps to pluck the cell debris and lasers to burn off affected areas. This is also a ripple effect of video camera technology.

Fig. 6.10 Japan's First Electronic Endoscope

6.9.3 Stereoscopic Video Camera

The world's first stereoscopic video camera, the SK3D7 shown in Fig. 6.11, was developed in 1987 and commercialized for the United States [(26)-(28)].

Fig. 6.11 The World's First Stereoscopic Video Camera

This was achieved by using the 300k pixel AI-30AF video camera shown in Table 6.4 as the base unit and adding compound eyes to the camera head. By accommodating precisely an integral structure with the two pairs of lenses and the CCD, left and right images were able to place with μ accuracy. The left and right images are retrieved in field sequential and recorded on an ordinary VCR. Playback is achieved by switching alternately left and right liquid crystal glasses in synchronization with the image, thereby and allowing viewers to easily enjoy a stereoscopic image. This camera is still widely used today.
Previous stereoscopic cameras comprised two cameras on a tripod and required careful adjustment to align the images. If the screen was even slightly displaced vertically, the left and right images could not overlap, and they become hard to see. This stereoscopic video camera, by introducing the technique of automatic adjustment jig to secure the high precision and CCD prism three-chip camera, it was possible to reduce the accuracy of the μ order or less error in the vertical direction. In this way, it was possible to obtain three-dimensional images successfully be affixed in the integral structure and CCD lens, stable easily at any time. To create a new camera, keeping the point of technology is necessary.

6.9.4 Intelligent Toys

Intelligent toys are expected as future applications of video camera technology. One such image is that of an intelligent doll that can give a simple response to women or senior citizens living alone who may want someone to talk to when coming home. Nursing robots that can monitor the elderly in need of constant care and quickly report any abnormalities can also be put to use in homes, care facilities and hospitals. The basic technologies common to these applications are video camera technologies themselves.

Fig. 6.12 The I-Doll, an Example of an Intelligent Toy

Fig. 6.12 shows the I-Doll (Intelligent Doll), an intelligent toy prototype applying laptop face recognition and Japanese language recognition to video cameras [(29)-(31)]. If you talk to the I-Doll, the video camera attached to the forehead of the doll detects the words, recognizes and understands the words, and display screen on the doll changes, while the speakers can enjoy conversation. It was prototyped in 1998, but it was too early for its time; it was costly and did not make it to commercialization.

6.9.5 Color TV telephone

The world's first color TV telephone was exhibited to the public in the Telecommunications Pavilion at the World Expo in Osaka in 1970. As shown in Fig. 6.13, this used a two-tube camera, with a camera on top, a receiver below and a small monitor mounted on the upper right section [(32)-(34)]. The camera was a highly sensitive 2/3 Chalnicon two-tube camera. A pair of these was displayed in the Telecommunications Pavilion for 180 days and could be freely used by the visitors. They could also be used for communicating between the Tokyo Kasumigaseki Building and the Osaka MM building as necessary.

Fig.6.13 The World's First Color TV Telephone

6.9.6 From the Cockpit Camera to the Video Camera

In the early 1980s, manufacturers worked hard to achieve mass production of CCDs. Sony's strategy was to start practical implementation from a small number of models, move on to business-use models and then lead up to full-scale mass production. Let us introduce its history.
During the transition period from pickup tubes to CCDs, Sony developed three types of cameras. The first of these was the XC-1. This was the world's first CCD color camera, commercialized in 1980, and it provided a stepping stone on the road to CCD mass production. It was used in aircraft, initially for the Sky Vision system in ANA jumbo jets, mounted in the cockpit and the forefoot landing gear. Sticking reason for CCD adoption had to overcome the weakness of the pickup tube, which is large size, vulnerable to shock and vibration. Since CCD was 120k pixels, resolution shortage was covered with 2-chip pickup system.
The second camera was the black and white XC-37, produced in 1983 on a full-scale CCD mass production line. This was the turning point in the transition from pick up tube to CCD. Ultra-small size that ride in the palm of the hand and anti-vibration shock resistance of the CCD unique, is called an overwhelming reputation in the commercial field, it became a long-selling machine in 15 years as a pioneer of machine vision camera.
In 1985, the CCD-V8 video camera adorned the final race of the conversion to a CCD from image pickup tube. It was also the originator of small video cameras built-in VCR. This camera recorded in the 8mm format, using a 250k pixel single-chip color CCD. It took five hard years of technological development from the time the prototype Video Movie was announced until it was completed. (Taken from interviews with Mr. Fumio Nagumo, formerly of Sony)

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7. Recording Equipment for Video Camera

7.1 Overview

Recording equipment for video cameras were provided separately from the camera and connected using a cable. This was inconvenient and progress was made on an integrating system called a camera built-in VCR that could be incorporated into a camera. However, since the cassettes themselves were too large in the existing Betamax and VHS formats, it was not possible to produce a video camera that was both small and easy to use. Therefore, several compact cassettes were proposed and standardized for cameras. This led to a flood of formats, such as 8mm, VHS-C, SVHS-C, DV and HDV. In addition, manufacturers also started making video cameras to suit their own specialty fields, such as DVDs, HDDs and SD cards, as well as VCR tapes.
Let us provide a simple overview of these here.

7.2 VCR

The first home-use VCR was the Unified I type that has been standardized as a technology standard of the EIAJ in 1969. It used an open-reel tape format rather than cassette type.
Later, tape cassettes is advanced, a variety of methods has been developed one after another. The U-matic format with its ¾ tape was commercialized in 1970, followed by the Unified I type cartridge VCR in 1972 and the V-cord format with its ½ tape in 1974.
Proper cassette VCR appeared in the form of the Betamax format by Sony in 1975 and the VHS format by JVC in 1976. Most stationary type VCR has been summarized in the two schemes.
An integrated VHS format camera was also released on the United States market. In Japan, Sony released an integrated VCR in 1983 in the Betamax format, with slightly smaller cassettes.
Later, improvements were made to the performance of NTSC peripheral devices and the 240 TV lines horizontal resolution of the VHS format was no longer sufficient. The S-VHS format was standardized in 1987, with the aim of achieving higher resolution.
By adopting the S terminal to be entered in YC separation, the resolution of the TV broadcast of the NTSC system while being constrained to 330 TV lines, 5MHz signal input is possible, horizontal resolution has become more than 400 TV lines.
On the other hand, as a target of the camera built-in type, in 1984, 8mm video aimed at the next generation of home use VCR has been standardized as a unified format of 127 worldwide companies.
In opposition to this, the group of VHS system has developed a VHS-C cassette for built-in cameras. However, since the recording time was as short as 20 minutes, VHS-C cassette was struggling to 8mm video that allows recording of 120 minutes.
The 8mm format later increased its performance with the Hi 8 and Digital 8 formats, and these systems using the compact cassette size, have spread to a video camera. Table 7.1 shows the tape widths and cassette sizes.

Table 7.1 Cassette Size and Tape Width

Item	Cassette size (mm)	Tape width (mm)
VHS	188×104×25	12.65
β	156×96×25	12.65
VHS-C	92×52×23	12.65
8mm video	95×62.5×15	8.00
DV	125×78×14.6	6.35
mini DV	66×48×12.2	6.35

The HD Digital VCR Council established the DV standard of digital recording VCR in 1995. In this standard, DV cassette standard size was 125 x 78 x 14.6mm, mini DV cassette size was 66 x 48 x 12.2mm, tape width was ¼ inch (= 6.35mm). As a result, image degradation due to dubbing which was trouble from the conventional could be reduced.
The HDV format was formulated for high-definition images, but at 1440 x 1080, this was not full high-definition, which required a horizontal resolution of 1920 pixels.

7.3 Digital Recording Media

There is nothing wrong with this as a standard, as this number of pixels still continues to be used for terrestrial digital broadcasting in Japan, although many people are not aware of this. By the way, broadcasting at 1920 pixels in the horizontal direction is only BS digital in Japan.
Following the standardization of the DVD in 1995, a succession of other digital recording media appeared, such as HDD and SD cards. Reliability has been significantly improved in the portable HDD which was a recording media of the original PC. A compact HDD with a diameter of 0.85 inches (around 22mm) was achieved in January 2004. This had 32 x 24 x 4mm cassette size and a capacity of 4GB. By June 2012, HDD capacity had reached 1.5TB. Fig. 7.1 shows an exterior view of the 0.85 inches HDD.

Fig. 7.1 0.85 inch HDD

Initially, it was a recording media of still images for digital cameras. With the advancement of semiconductor technology, recording capacity of the SD card continue to increase year by year, the capacity of 64GB has been achieved in the standard type in 2012.
Compared to conventional magnetic tape recording, these digital recording media offered significant advantages, such as not requiring a complicated mechanism, significantly improved reliability and superior access. Video cameras using these recording media were

commercialized in succession, while VCR video cameras with their complicated mechanisms rapidly began to disappear.

7.4 Video Cameras using Digital Recording Media

Sony and JVC put out DV format video cameras in 1995. They were spotlighted since image quality is not degraded by the editing and dubbing.
In 2003, the first high-definition video camera was released by JVC. However, this did not gain popularity, since scanning line of this camera had only 720 lines against standard 1080 lines. 1080i high-definition camera was released for business use from Sony in 2004. This was a HDV format business-use model, but it was followed by the release of a home use high-definition camera in 2005.
In 2007, Panasonic brought out a high-definition video camera with an SD card, while Toshiba released a high-definition video camera with an built-in HDD. Other manufacturers hit the markets with their own video cameras, using their own preference of recording media. Even Sony, which had persisted with the HDV format, brought out a video camera in 2010 with the tape replaced by memory recording.
Specifications of these recording media are shown in Table 7.2.

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Table 7.2 Digital Recording Media

System	Recording media	Capacity	Number of pixels
DV	Magnetic tape	12.9GB/hour	720×480
HDV	Magnetic tape	Ditto	1440×1080,1280×720
AVCHD			1920×1080, 1440×1080, 1280×720, 720×480, 720×576
DVD	80mmDVD	2.8GB (Both sides) BD 7.5GB	
Digital	SD card	64GB	
Digital	HDD	1.5TB	

1.5TB: 408,000 photographs (at 3.5MB each); 1200 movies (at 13MB/minute, 90 minutes/movie); 159 hours of digital TV; 381,000 music songs (MP3 compression 128kbps, 4 minutes/song)

8. High Function Technology

8.1 Overview

Electronic circuits in video cameras can be roughly divided into circuits concerning image quality and high function. Research and development on this circuit technology was carried out in the 1960s and 1970s, mainly in relation to broadcasting cameras. This technology has contributed greatly to color camera performance. After that, the race to develop the home use video camera became violently when it comes to the 1970s. As an application of image processing technology, electronic circuits of high functionality and image quality were advanced by Japanese engineers. First, the key technology for high functionality will be introduced here. High functionality technologies of video camera mainly comprises auto exposure (AE), auto focus (AF), auto white balance (AWB), auto stabilizer (AS), face recognition and flicker removal, as shown in Fig. 10.1.

8.2 AE

The first AE patent is said to be by Jullius Durst (AGFA, Germany) [1] in 1955, shown in Fig. 8.1. It was intended to control the shutter speed of the camera by detecting the brightness.
While this camera had a separate photometric sensor, this would measure the ambient light, making it impossible to accurately measure the brightness of the object.
Since cameras now have a high performance sensor namely an image sensor, as shown in Table 8.1, light intensity is controlled by using the output signal of the image sensor.

Table 8.1 Auto Exposure Method

Method	Detector	Principle
Ambient Light	Spot Sensor	Simple Measurement
Object	Image Sensor	Average Measurement
		Weighted Measurement

Output signal increases if the subject is brighter, and decreases if darker. Keeping this at a constant level requires a means of controlling the amount of incident light, either by changing the lens aperture or by controlling the electronic shutter speed.
Nowadays it is common to use a program to alter both of these. Simple photometry by averaging the whole frame of the subject is rarely used now. Current methods use weighted metering, in which the subject frame is divided and the metering is carried out on the more important areas, and face recognition AE, in which the face area of a person being taken is selected by face recognition and then metering is carried out on that area.

8.3 AF

AF technology has been used from the earliest cameras. The Konica C35AF released in 1977 was very popular, nicknamed the Jaspin Konica. This was the world's first AF camera, using a module developed by Honeywell [2]. This mechanism, called the TCL (Through the Camera Lens) method [4], divided the light passing through the lens into two images and then detected the phase difference between the resulting two images, as shown in Fig. 8.2.

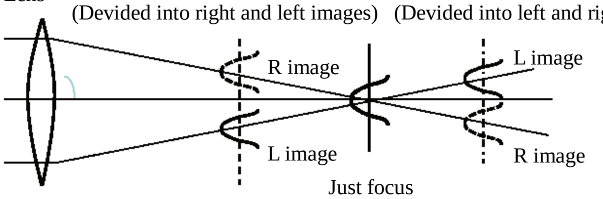
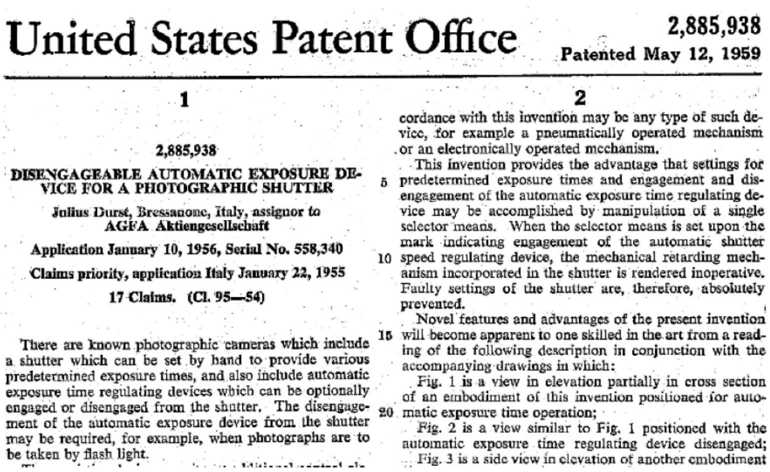


Fig.8.2 TCL Method [4]



United States Patent Office

2,885,938

Patented May 12, 1959

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2,885,938

DISENGAGEABLE AUTOMATIC EXPOSURE DEVICE FOR A PHOTOGRAPHIC SHUTTER

Julius Durst, Bressanone, Italy, assignor to AGFA Aktiengesellschaft

Application January 10, 1956, Serial No. 558,340

Claims priority, application Italy January 22, 1955

17 Claims. (Cl. 95—54)

There are known photographic cameras which include a shutter which can be set by hand to provide various predetermined exposure times, and also include automatic exposure time regulating devices which can be optionally engaged or disengaged from the shutter. The disengagement of the automatic exposure device from the shutter may be required, for example, when photographs are to be taken by flash light.

2

cordance with this invention may be any type of such device, for example a pneumatically operated mechanism or an electronically operated mechanism.

This invention provides the advantage that settings for predetermined exposure times and engagement and disengagement of the automatic exposure time regulating device may be accomplished by manipulation of a single selector means. When the selector means is set upon the mark indicating engagement of the automatic shutter speed regulating device, the mechanical retarding mechanism incorporated in the shutter is rendered inoperative. Faulty settings of the shutter are, therefore, absolutely prevented.

Novel features and advantages of the present invention will become apparent to one skilled in the art from a reading of the following description in conjunction with the accompanying drawings in which:

Fig. 1 is a view in elevation partially in cross section of an embodiment of this invention positioned for automatic exposure time operation;

Fig. 2 is a view similar to Fig. 1 positioned with the automatic exposure time regulating device disengaged;

Fig. 3 is a side view in elevation of another embodiment

Fig.8.1 AE Basic Patent [1]

In addition, there was a patent dispute between Minolta and Honeywell.
The two companies had initially been promoted in the joint, but the development speed was too slow. In the meantime, Minolta developed its own system and installed it in a single-lens reflex camera, the Alpha 7000.
As a result, this camera became a violation of Honeywell's patent [7] [8].

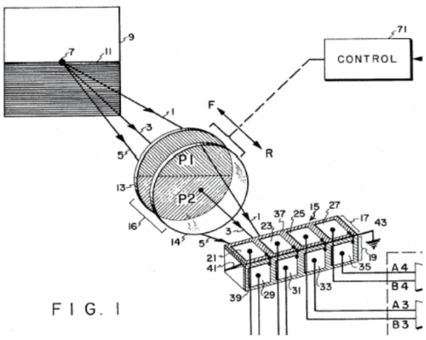


Fig.8.3 Honeywell AF Patent [7]

The patent is shown until control means using the output signal of the TCL, as shown in Fig. 8.3. Although the principle of the TCL method is also shown in a patent by German company Leitz [9], it does not mention the control means, as shown in Fig. 8.4.

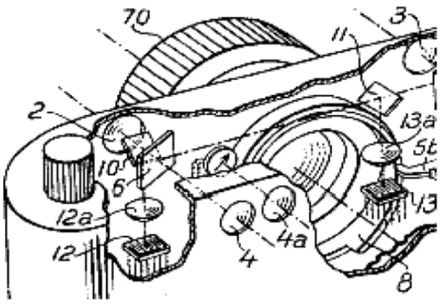


Fig.8.4 Leitz AF Patent [8]

AF technology then advanced in two general directions, as shown in Table 8.2: the contrast method to maximize the video signal contrast and the phase difference method.

Table 8.2 Auto Focus Method

Method	Detector	Control	Principle
Active	Ultrasonic	Lens Focus	Propagation velocity
	Infrared	Lens Focus	Triangle
Passive	TCL	Lens Focus	Phase detection
	Image signal	Lens Focus	Phase difference & Image Contrast
Light Field	None	None	Image processing

Fig. 8.5 Scene with Depth

Here, when we go back to the origin of the AF, the object has originally 3-D depth, as shown in Fig. 8.5. Where the camera focuses depends on the wishes of the photographer. It is due to the intention of the photographer where he wants to focus. It is therefore not possible to achieve perfect AF through any simple means.
The first method considered was center-weighted metering, selecting the center of the frame and focusing there on the assumption that the photographer would position the desired subject in the center of the frame. However, there was a flaw with this method in that if the photographer were capturing a scene in which a toast was being proposed, for example, the camera would focus on the mug of beer and blur out the all-important people in the shot. Accordingly, a more recent method has been to use face recognition technology to focus on the faces.
Hill-climbing control is often used in basic AF control technology. The amplitude of the high frequency component of the video signal maximizes at the focus position, on the contrary, the amplitude decreases for rear focus or in the front. This relationship is shown in Fig. 8.6. It is called a hill-climbing servo, as it means to climb the top of the mountain, and is also a technique from Japan [10].

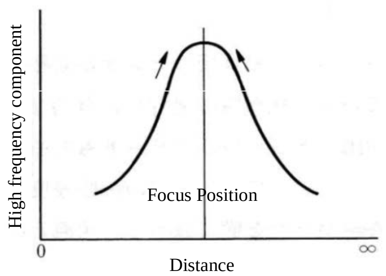


Fig. 8.6 Hill-Climbing Control

Digital control by microcomputer has been carried out in practice in recent years.
After integrating the high-frequency components over one field period, the lens is moved as this value come to be largest.

While it is simple in theory, in practice if you do not move it one way or another, you cannot know whether it is in focus or not. Also, you cannot check that the signal amplitude is at its maximum value, even if it is in focus, or at the top of the hill. Since the maximum value of the amplitude is highly dependent on the object, no absolute value can be determined. Also, when the object moves, the speed to follow becomes a problem. Since the value

is obtained by integrating each field, the time of several fields is required for detection at a minimum.
New light field technology [(11)-(13)] is notable in the recent field of AF. This technique is intended to reproduce an image by converting Fourier transform image formed on the rear surface of the lens, using electrical processing. Since the image sensor is placed in the imaging position, an optical image entering the pixels is usually obtained by integrating the light passed through the entire surface of the lens. As a result, any original angle information was lost. On the other hand, in the light field technology angle information is actively utilized. More specifically, by placing a microarray lens to image plane, a plurality of images having angular information is imaged on the image sensor. Using this system to capture a subject means it is possible to adjust the focus position according to the preference of the photographer by using the angle information in the image and processing the image accordingly.

8.4 AWB

The color in an image varies according to the light conditions even if the photographic subject is the same, for instance, under sunlight outdoors, in cloudy weather, under white lamp indoors or under fluorescent lights.

Since the human eye is capable of adapting to different light conditions to make white feel like white even in different lighting, these different conditions do not feel unnatural. However, cameras faithfully reproduce the RGB components contained in the light even under different color temperatures. If the color temperature is high, as shown in Fig. 8.7 (a), the camera reproduces a bluish white, while if the color temperature is low, as shown in Fig. 8.7 (c), then the camera reproduces a reddish white.
In many cases, it is necessary to control the white balance in the camera when the color temperature changes, because white must appear as white, as shown in Fig. 8.8. For an achromatic subject, this is adjusted so that the RGB ratio is always constant or so that the color difference signals R-Y and B-Y become always zero. As shown in Fig. 8.9, the color temperature is detected by viewing the balance of the RGB signal. If the color temperature is high, the B gain goes to reduce and if the color temperature is low, the R gain goes to reduce.

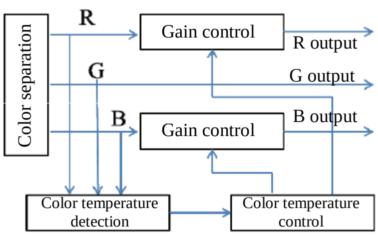


Fig. 8.9 Block Diagram of AWB (Auto White Balance)

(a) Higher color temperature +2700K

(b) Original picture

(c) Lower color temperature -2300K

Fig.8.7 Color Changes due to Color Temperature

(a) Fine weather scene

(b) Cloudy weather scene

(c) Indoor scene lit by light bulb

Fig. 8.8 Preferred Color Tones for Changes in Color Temperature

It is necessary to detect the color temperature accurately in this case. Ideally, a white reference, such as Mg paint is placed in front of the lens and then takes a white balance for the camera.
However, this is too much of combersome for ordinary camera users, so the white is determined using the features of the photographic subject.
For example, it can be based on the assumption that if all the colors in a scene are integrated, they will generally approximate to zero and come close to an achromatic color.
In this case, only the low saturation component in the scene needs to be integrated after the high saturation colored portion is excluded.
Using such methods increases the accuracy of the color temperature detection. In some specific scenes, the AWB function can be dispensed with due to the particular characteristics of the subject to avoid producing an unnatural image, such as a sunset scene with an overall red color, or a close-up of a tomato.
In practice, there are not many different types of color temperatures, so cameras can be pre-configured with several different correction coefficients, such as for incandescent lamps, fluorescent lamps or sunlight, and these can be switched to produce a white balance that is close to optimal.
For further details on this technology, refer to the cited literature (14) - (19).

8.5 Image Stabilization

Image stabilization technology to electronically correct camera shake was first put to practical use in broadcasting in 1987 (20) (21). This electronic image stabilization system removes shaking by scanning the image signal for screen shake and vibration, quantifying this in terms of parallel displacement of the overall image, and then correcting the position of the screen based on this information.
As shown in Fig. 8.10, this method involves identifying a motion vector from the video signal, generating a correction vector and translating the image position.

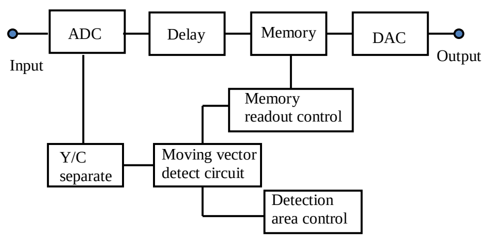


Fig. 8.10 Block Diagram of an Image Stabilization Apparatus (20)

Anti-vibration device is required for camera photographing from moving objects, broadcasting images from a hand-held camera while were difficult to view, this device was able to improve these images.
While image stabilization is now a standard feature on digital cameras, in 1987 semiconductor technology was not as advanced as it is now; this device required a portable rack, as shown in Fig. 8.11.

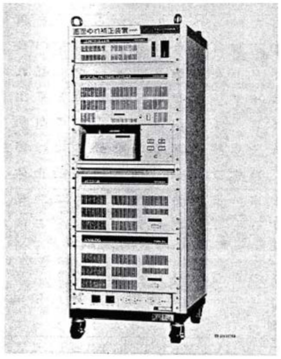


Fig.8.11 Early Image Stabilization Apparatus (20)

The need for video camera image stabilization is beginning to be recognized since the late 1980s, with much research and development taking place in this field (22). The gimbal mechanical method (23) (24) shown in Fig. 8.12 was first commercialized for video cameras.

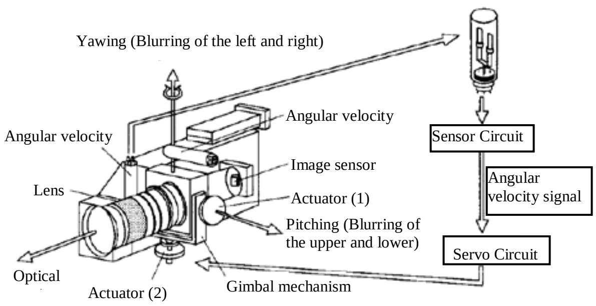


Fig. 8.12 Gimbal Mechanical System (22)

A major factor causing camera shake in hand-held shooting is due to the vibration below 20Hz (23). First, a band extraction filter is used in both the horizontal and vertical directions to extract the frequency component effective for motion detection from the video signal. Next, a band extraction representative point matching method is used to extract the motion vector more efficiently (25) (26).
Fuzzy logic is used to differentiate between hand shake and subject movement to avoid false operation (27).
A system for correcting blurring in CCD cameras was patented in 1980 (28).
Many kinds of image stabilization systems have since been researched and developed (29)-(86).

8.6 Face Detection and Recognition

The face is the most important subject in camera shooting. According to statistics, 70% is taken around the face [87]. Thus, as it becomes increasingly necessary to take photos with no failure, by matching the exposure, focus and color tone centered on the face, the number of cameras with face detection features is increasing.
Face recognition technology was first installed on three models in Nikon’s COOLPIX series launched in February 2005, the 7900, 7600 and 5900. These cameras adopted Face IT, a face recognition technology developed by Identix (Minnesota, USA) using biometric technology. This was the world’s first face recognition AF in a compact digital camera, capable of detecting and focusing on human faces in the shooting scene [88].
In September 2006, Fujifilm released the Fine Pix S6000fd digital camera, equipped with a face detection feature called Intelligent Face. An announcement was made stating that image processing software, Image Intelligence was capable of detecting up to 10 people at a time. The detection speed was the world's fastest [89].
Digital camera with face recognition was released one after another when it comes to 2007. Pentax with the Optio A30 in February, Sony with the Cyber-shot T100 in March, Olympus with the µ780 in April, Canon with the IXY DIGITAL 810IS in June, and Casio with the EXILIM ZOOM EX-Z1200 in June.
Technology emerged in the fall of 2007 that could not only detect a face, but also a smile.
Sony released the Cyber-shot DSC-T200 and DSC-T70 in September 2007, equipped its own "Smile Shutter" and designed to shoot without missing a natural smile [90].
Omron developed real-time smile measurement technology to measure the smile degree from the facial image [91], as shown in Fig. 8.13. This was in turn followed by the release of the CAMEDIAFE-320 by Olympus in January 2008, a camera with a Smile Shot to automatically capture a smile using continuous shooting [92].

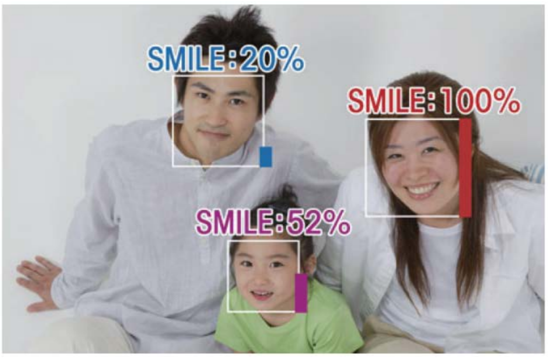
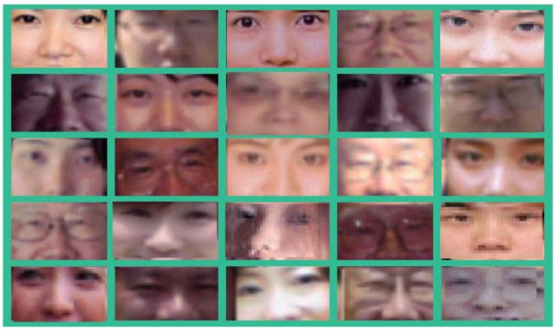
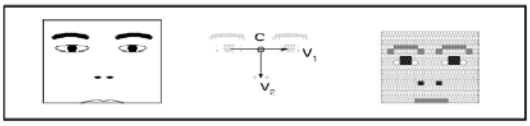


Fig. 8.13 Image using Smile Measurement Technology of Omron’s OKAO Vision [89]

In January 2008, Panasonic released the world’s first face-recognition high-definition digital video camera HDC-SD9 / HDC-HS9. This was equipped with automatic face recognition that detects people’s faces while capturing moving images and automatically performing the appropriate adjustments, meaning effortless operation by the user [93]. In April the same year, Sony built a face recognition function into its digital high-definition camera HDR-TG1 to allow clear capturing of faces [94].
Face recognition technology has long been promoted for safety applications for a long time such as for gate entry checks and detecting suspicious persons at airport gates, as well as for gathering personal statistics on viewers for television audience research. These applications use a database of stored faces of individuals, with the aim of matching the face of the person in front of the camera to a face stored in the database. Therefore, it is necessary to increase the accuracy rate.
By contrast, camera face recognition technology is far simply technically, as it only captures the face. Let us introduce this technology.
The camera has to accurately detect the face area within the captured scene (photographic subject). Generally, a face database is provided to distinguish between face and non-face images. Facial features, such as the eyes, nose and mouth are characterized by their location, end points and center points, while the chin, nose, eyes, eyebrows and mouth are characterized by their shape and contours. Face detection is performed by combining these features.
In this example, the identifier has a database of facial images, as shown in Fig. 8.14 (a), and learns to distinguish between face and non-face images. Next, the camera focuses on the eyes and the nose, as shown in Fig. 8.14 (b), and determines an approximate positional relationship, with three additional characteristics.

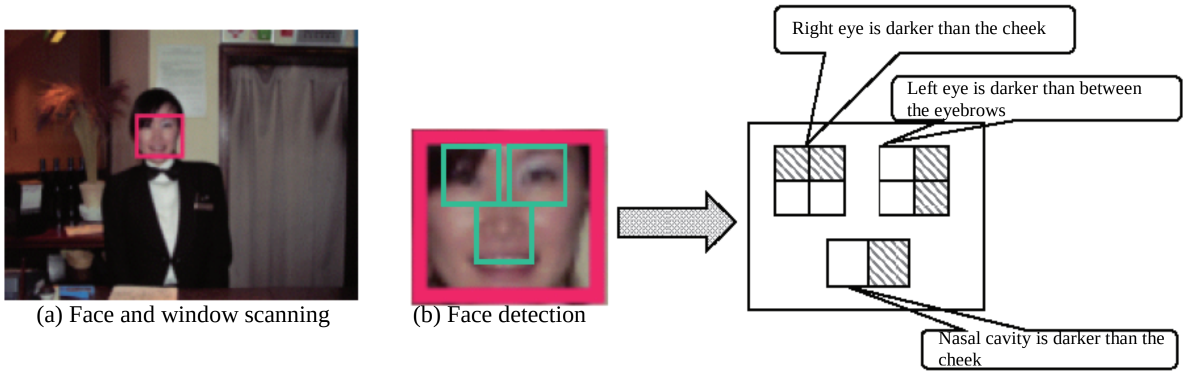


(a) Example of a face dictionary



(b) Feature point extraction

Fig. 8.14 Example Face Dictionary, created with reference to literature (95)



(a) Face and window scanning (b) Face detection

Fig. 8.15 Example of Face Detection Processing

The right eye is darker than the cheeks; the left eye is darker than the eyebrows; the nose is darker than the cheeks. This can be represented as three groups of light and dark rectangles. Each group is called Haar Wavelet characteristics. Final determination is carried out using a boosting learning algorithm.

This fulfilling of multiple characteristics simultaneously is called co-occurrence and has contributed to improving detection accuracy [95]. Methods using partial contrast include using the eyes and mouth [96]. One such example is shown in Fig. 8.15.

For more detailed information on this technology, refer to the cited literature [97]-[103].

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9. High Image Quality Technology

Following on from Chapter 8, let us describe the high quality technology of video camera electronic circuit.
As shown in Fig. 10.1, which provides a summary of all video camera technology, these electronic circuits include the basic camera circuits, such as a color separation circuit, color signal processing and luminance signal processing, as well as contrast correction, dynamic range expansion, demosaicing and super-resolution processing.

9.1 Contrast Correction

Recent advances in digital imaging technology have opened new ground in the fields of image recognition and image processing.
In the conventional analog approach, backlight correction, edge or certain signals enhancement would increase the noise to the same extent. In many cases, this would result in an overall noisy image, despite the desired effect having been achieved, leaving the general impression that the image quality had not been significantly improved.
Digital processing has made it easier to perform frequency domain image processing based on the Fourier transform. It has also made it possible to apply various filtering by manipulating the frequency domain, as well as digital processing using mathematical functions.
British company Apical Limited entered this area early on and has been working to improve the image quality of digital cameras and surveillance cameras (1). Apical uses a method of improving image quality by means of appropriate contrast correction of the black and white components in a signal that have been lost during the compression and recording of the signal. It is possible to correct the contrast in advance, so that the input signal will not exceed the contrast range of the display device.
It is also possible to obtain a high quality image with the desired properties improved by dividing the input image into illumination light component and object light component, based on Retinex theory (2) shown in Fig. 9.1, and then combining the two after processing them separately (3). While this principle was proposed in the 1970s, advances in digital image processing paved the way for active research and development by NASA in the 1990s. In the 2000s, the enabling of high integration and high speed digital processing led to its use in consumer applications.

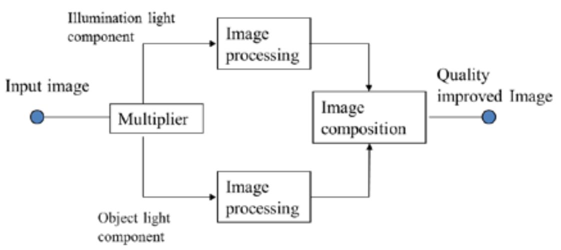


Fig. 9.1 Retinex Principle

To achieve the intended purpose, a multiplier is used for the separation of the input image, while ε filters and other various digital filters and functions are used for processing the image. These sophisticated arithmetic processing was strongly performed (4) (5).
For example, the contrast of the input image can be optimized after separation by compressing the level of the illumination light component and expanding the object light level, as shown in Fig. 9.2.

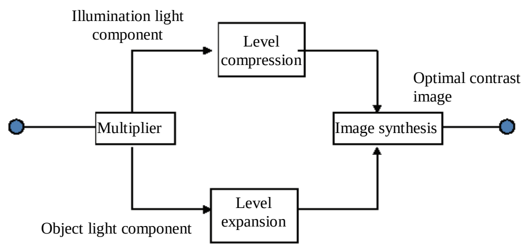


Fig. 9.2 Adaptive Contrast Enhancer (ACE)

After the multiplier separates out the texture generators and skeleton image and the processing as shown in Fig. 9.3 is applied, a high-quality expanded image can be obtained with (1) no peripheral edge ringing, (2)no sample hold blur, (3) suppressed jaggy edges (6).

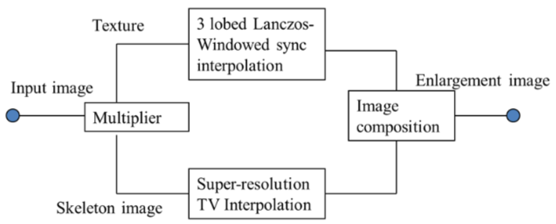


Fig. 9.3 Image Expansion Application, compiled with reference to literature (6)

Performing the processing shown in Fig. 9.4 can also produce a high-quality image by removing only noise without dulling the sharp edges and without generating ringing or jaggy edges (6).
On the other hand, by utilizing these images processing technology, electrically lens blur correcting was developed for practical use (7).

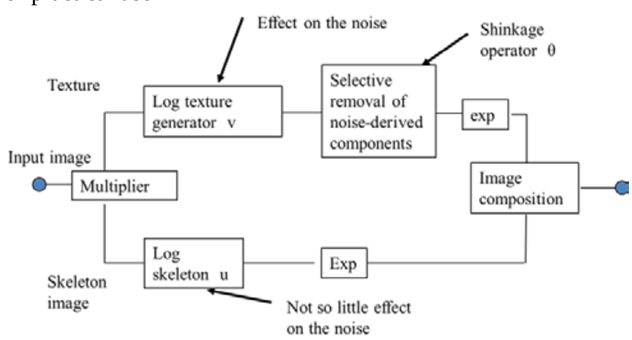


Fig. 9.4 Noise Reduction Application,
Summarized by literature (6)

9.2 Dynamic Range Expansion

The dynamic range is the extent to how the dark areas and light areas can be reproduced when these areas are mixed within a single image. In other words, dynamic range is measured as the ratio between the light and dark areas. Figure 9.5 illustrates the photoelectric conversion characteristics of the image sensor. Bright level of the output signal is limited by the saturation by the input excessive light. On the other hand, dark level is limited by the signal buried in noise when the input light is dark.Therefore, expanding the dynamic range basically requires raising the saturation level and lowering the noise level.

The IT-CCD (interline transfer CCD), most common used in cameras today, has a dynamic range of 60-70dB. However, since intensity of light is much wider than this, on-vehicle cameras require a dynamic range of about 120-130dB to handle without inconvenience in nature.

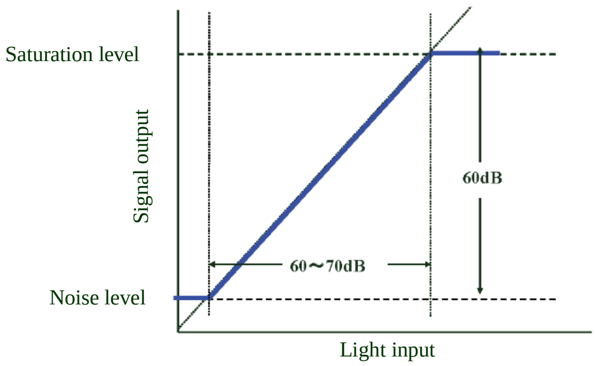


Fig. 9.5 Image Sensor Photoelectric Conversion Characteristics

Expansion of the dynamic range is a very important development challenge in camera technology and various efforts have been made in this area since the 1980s, primarily in improving image sensor technology [8]. However, in many cases, the basic characteristics of the image sensor are impaired and so it has not been used practically into actual cameras.

As shown in Fig. 9.6, dynamic range expansion is desired where the contrast range is extremely wide at the entrance and exit of the tunnel [9] [10]. In Fig. 9.6 (a), the inside scene of the tunnel cannot be seen, while in Fig. 9.6 (b) the outside scene of the tunnel cannot be seen.

(a) At the entrance, the interior is dark and cannot be seen very well

(b) Inside, the exterior is so bright and cannot be seen very well

Fig. 9.6 Images of a Tunnel Entrance and Exit

Various methods of dynamic range expansion technology have been proposed and tested, as shown in Table 9.1. However, since it affects the basic characteristics of the camera, it has rarely been installed on actual video cameras. It has been put to practical use in some professional cameras, installed on station platforms [11] [12] and monitoring scene and person with highly variable levels of sunlight [13] [14].

Fig. 9.7 shows a frame of an image taken with a wide dynamic range (WDR) camera adaptively using multiple electronic shutters. While the outside view cannot be seen in the image taken with an ordinary camera, as shown in Fig. 9.7 (a), this camera can recognize both the inside and the outside of the tunnel, as shown in Fig. 9.7 (b).

Table 9.1 Various WDR Methods

Item	Method	Means
Basic characteristics	Expansion of the saturation level	Pixel area expansion, etc.
	Reduction of the noise level	Dark current reduction, etc.
Pixel configuration	Logarithmic characteristics [15]-[20]	Use of MOS FET threshold characteristics
	Lateral overflow capacity [21]-[26]	Re-accumulate overflow charge
	Vertical 2-pixel method [27] [28]	High sensitivity and low sensitivity pixels arranged vertically
	ADC in each pixel [13] [14]	Each pixel signal has a different exposure time through ADC
Camera technology	Sweep-out drive [29]	Remove part of the accumulated charge
	Multiple electronic shutter [30]-[32]	Time division of high-speed shutter and low-speed shutter

(a) Image using normal camera

(b) Image using WDR camera

Fig. 9.7 Image comparison of using normal camera and WDR camera [32]

CMOS image sensors made it possible to configure the transistor and capacity at pixel level, meaning it was now possible to implement various types of WDR using pixel structures that were not possible with CCDs. Thus, various methods have been proposed [33]-[36].
Refer to the cited references for details, as there is no space to describe each method in detail in this paper.

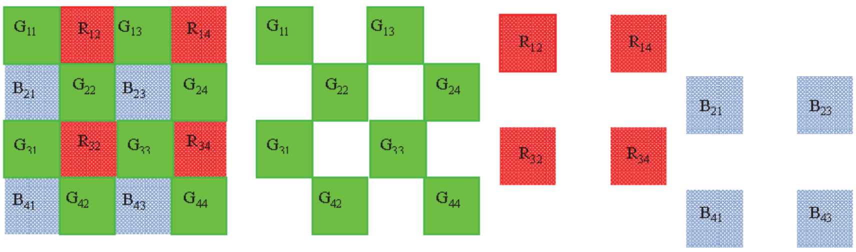
9.3 Demosaicing

The Bayer array shown in Fig. 9.8 (a) comprises the respective color components shown in Fig. 9.8 (b) – (d). G is arranged in a checkerboard pattern, and occupies twice as many pixels as R and B.
Thus, any pixels lacking color information must be filled in to obtain a color signal from the separately-arrayed color information. By the method how to fill the pixel, relations of the spurious signal and the resolution of the image is greatly changed, and the effects on image quality is large.

Since camera signal processing was analog in the 1970s and 1980s, a method of obtaining a RGB signal was limited. For example, image quality have been improved by Onga by using 4 lines of 1H delay then using line correlation to obtain two color difference signals and the luminance signal [37] [38].
Later, digital signal processing contributed greatly to improving image quality in this field. From the early 1990s, Kodak, which had received much early attention for producing the Bayer method, proposed patents for various plausible methods for filling pixels. Advances in computing made it relatively easier to simulate resolution and false signals, resulting in a clear color image. Universities and various research laboratories joined manufacturers in turning their research focus on this. Numerous patents and academic reports came to be made as a result [39] [40].
These techniques became to be known as demosaicing, which recovers the new signal from sampled mosaic signals.

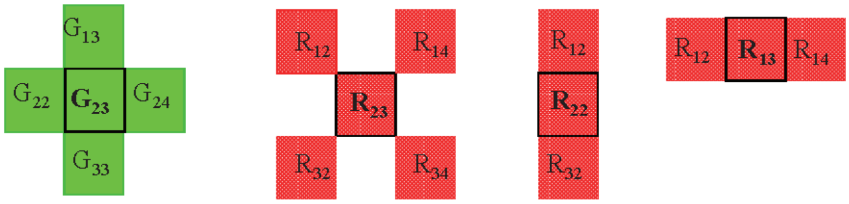
9.3.1 Simple Interpolation

As shown in Fig. 9.9 (a), the G component could be always made up from 4 pixels around interpolated pixels. Therefor, G component on G_{23} position could be interpolated from 4 kinds of G pixels existing arround G_{23} position.
In contrast, as shown Fig. 9.9 (b)-(d), depending on the position of the R, the interpolation of the R component are three ways, such as a cross of 4 pixels, a vertical column of 2 pixels or a horizontal row of 2 pixels.
At first, as shown in Fig. 9.9 (b), R component on R_{23} position has to be interpolated from R four pixels existing diagonally.
Meanwhile, R_{22} and R_{13} are respectively interpolated by the 2 vertical or horizontal pixels, as shown in Fig. 9.9 (c) and (d). The B component also can be interpolated in the same way as the R component.
That is, G in the case of performing a simple linear interpolation, becomes followings,
$G_{23} = (G_{13} + G_{22} + G_{24} + G_{33}) / 4$.
Meanwhile, with cross interpolation, R or B become followings,
$R_{23} = (R_{12} + R_{14} + R_{32} + R_{34}) / 4$



(a) Bayer Array (b) G component (c) R component (d) B component

Fig. 9.8 Bayer Array and RGB Color Components



(a) Interpolation of G
$G_{23} = (R_{13} + R_{22} + R_{24} + R_{33}) / 4$

(b) Cross interpolation1of R
$R_{23} = (R_{12} + R_{14} + R_{32} + R_{34}) / 4$

(c) Vertical interpolation1of R
$R_{22} = (R_{12} + R_{32}) / 2$

(d) Horizontal interpolation of R
$R_{13} = (R_{12} + R_{14}) / 2$

Fig. 9.9 Each Color Component Interpolation

With vertical interpolation, $R_{22} = (R_{12} + R_{32}) / 2$.
With horizontal interpolation, $R_{13} = (R_{12} + R_{14}) / 2$.
However, this method is a so-called smoothing and only achieves a simple LPF effect. Accordingly, while there is no problem in areas where there is no change in the image, there is significant error at edges or in textures. Thus, the following improvements have been proposed to reduce the error.

9.3.2 Adaptive Interpolation

Adaptive Interpolation method that interpolates by determining the direction of the edge has been proposed by Robert H. Hibbard (Eastman Kodak) [41]. At first, when interpolating the G23 in Fig. 9.9, to see the surrounding G pixel, this technique determine the preferred direction of interpolation. This method calculates the vertical and horizontal G gradients and interpolates using pixels in the direction of less change, with the assumption that the change will be greater in the direction with the higher gradient. Specifically, the following equations are used for calculation.

$$\Delta G_v = | G_{13} - G_{33} |$$
$$\Delta G_h = | G_{22} - G_{24} |$$

Here,
if $\triangle G_h > \triangle G_v$ $G_{23} = (G_{13} + G_{33}) / 2$
if $\triangle G_v > \triangle G_h$ $G_{23} = (G_{22} + G_{24}) / 2$

Other than the above case $G_{23} = (G_{13} + G_{22} + G_{24} + G_{33}) / 4$.

While the above method looks at the gradient across 2 pixels, applying the color information makes it possible to determine the gradient across 3 pixels, thereby improving the recognition accuracy. The above method patent was proposed on the same day as the above method by Mark A. Prescott and Claude A. Laroche (both Eastman Kodak) [42]. As shown in Fig. 9.10, this method is performed to determine the gradient by calculating the surrounding R pixels when interpolating G_{34} to the position of the R_{34} pixel. While this method looks at the gradient across 2 pixels when interpolating only G pixels, the gradient across 3 pixels can be taken into account by using the R pixel, thereby the prediction accuracy is increased.

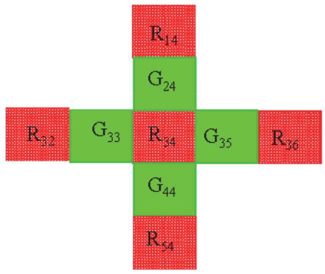


Fig. 9.10 An Example of Interpolation with Consideration of Edge Directions of the Color Information [42]

$$\Delta R_v = | (R_{14} + R_{54}) / 2 - R_{34} |$$
$$\Delta R_h = | (R_{32} + R_{36}) / 2 - R_{34} |$$

Here,
if $\triangle R_h > \triangle R_v$ $G_{34} = (G_{24} + G_{44}) / 2$
if $\triangle R_v > \triangle R_h$ $G_{34} = (G_{33} + G_{35}) / 2$

Other than the above case $G_{34} = (G_{24} + G_{33} + G_{35} + G_{44}) / 4$

Similarly, when interpolating G_{23} to the position of the B_{23} pixel under the same conditions, the gradient can be determined by calculating the surrounding B pixels.
An interpolation method that looks at the direction of the edge has also been proposed using the Jacobian array [43].

9.3.3 ACPI (Adaptive Color Plane Interpolation)

The ACPI method was proposed by John F. Hamilton, Jr. and James E. Adams, Jr. (both Eastman Kodak) as a method to increase the accuracy of the interpolation using the gradient and Laplacian (second-order differential) by combining the G pixels with either the B or R pixels [44]. As shown in Fig. 9.11, this method involves adding the G gradient and R Laplacian when determining the change in G.

$$\Delta G_v = | G_{24} - G_{44} | + | 2R_{34} - R_{14} - R_{54} |$$
$$\Delta G_h = | G_{33} - G_{35} | + | 2R_{34} - R_{32} - R_{36} |$$

Here,
if $\Delta G_h > \Delta G_v$, then
$G_{34} = (G_{24} + G_{44}) / 2 + (2R_{34} – R_{14} – R_{54}) / 4$
if $\Delta G_v > \Delta G_h$, then
$G_{34} = (G_{33} + G_{35}) / 2 + (2R_{34} – R_{32} – R_{36}) / 4$

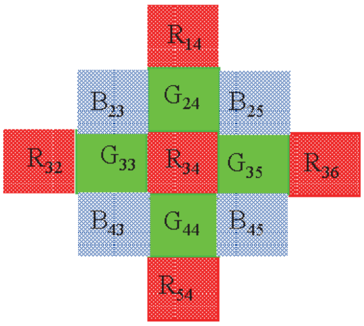


Fig. 9.11 Explanatory Diagram of ACPI System [44]

Other than the above case
$G_{34} = (G_{24} + G_{33} + G_{35} + G_{44}) / 4 + (4R_{34} – R_{14} - R_{32} – R_{36} – R_{54}) / 8$.

On the other hand, for the B and R pixels, B pixel will be described for example.

Vertical interpolation,
$B_{33} = (B_{23} + B_{43}) / 2 + (2G_{33} - G_{23} - G_{43}) / 2$

Horizontal interpolation,
$B_{24} = (B_{23} + B_{25}) / 2 + (2G_{24} - G_{23} - G_{25}) / 2$

There are three types of interpolation of the cross direction.
In the case of a downward sloping,
$B_{34N} = (B_{23} + B_{45}) / 2 + (2G_{34} - G_{23} - G_{45}) / 2$

In the case of an upward sloping,
$B_{34P} = (B_{43} + B_{25}) / 2 + (2G_{34} - G_{43} - G_{25}) / 2$

If an average value,
$B_{34A} = (B_{23} + B_{25} + B_{43} + B_{45}) / 4 + (4G_{34} - G_{23} - G_{25} - G_{43} - G_{45}) / 4$.

There are different types of determination for upward or downward sloping.

In the case of a downward sloping,
$DN = | 2G_{34} - G_{23} - G_{45} | + | B_{23} - B_{45} |$;

In the case of an upward sloping,
$DP = | 2G_{34} - G_{25} - G_{43} | + | B_{25} - B_{43} |$.

So, in the case of DP > DN,
$B_{34A} = (B_{23} + B_{45}) / 2 + (2G_{34} - G_{23} - G_{45}) / 2$
If DN > DP,
$B_{34P} = (B_{43} + B_{25}) / 2 + (2G_{34} - G_{43} - G_{25}) / 2$.
If DP ≒ DN,
$B_{34A} = (B_{23} + B_{25} + B_{43} + B_{45}) / 4 + (4G_{34} - G_{23} - G_{25} - G_{43} - G_{45}) / 4$

A similar interpolation is performed for the other color signal, in this case, the R pixels.

9.3.4 CHBI Method (Constant Hue Based Interpolation)

Sections 9.3.1 to 9.3.3 were methods of interpolating pixels. The CHBI method proposed by David R. Cok (Eastman Kodak) generates new pixels by replacing pixel contrast [45]. This method makes use of the image property in which changes in hue are uniform in uniform images and the color ratio also becomes substantially constant.
Accordingly, R and B pixels are generated by finding the ratio of the two colors from the surrounding pixels and replacing the pixel with the average value of this ratio.
Missing G pixels are first interpolated by the interpolation methods described in 9.3.1-9.3.3.
Next, R and B pixels are generated. However, since these are the same, only R generation is shown here. Using the Bayer method, there are three ways of locating the position of missing R pixels, as shown in Fig. 9.9. In Fig. 9.9 (c), the position (2, 2) is generated, using the ratio of the vertical neighboring.
Followings are obtained.

$$R_{22} = G_{22}\left(\frac{R_{12}}{G_{12}} + \frac{R_{32}}{G_{32}}\right) / 2$$

Since a signal of the position (1, 3) is generated in Figure 9.9 (d), using ratio of the horizontal both sides,

$$R_{13} = G_{13}\left(\frac{R_{12}}{G_{12}} + \frac{R_{14}}{G_{14}}\right) / 2$$

On the other hand, since a signal of the position (2, 3) is generated in Fig. 9.9 (b), if the ratio of the 4 pixels in the cross is used, then

$$R_{23} = G_{23}\left(\frac{R_{12}}{G_{12}} + \frac{R_{14}}{G_{14}} + \frac{R_{32}}{G_{32}} + \frac{R_{34}}{G_{34}}\right) / 4$$

All pixels can be generated.
The B pixels in the other color signal can be generated in a similar manner.
In addition, the Cop method is a good approach for interpolating a few R and B pixels using the G pixels.
Another method was proposed in 1984 [46] to improve R and B pixel interpolation and reduce false signal (color fringing) by calculating the color component of the R and B pixels using the G component.

9.3.5 Improvement using the edge indicator

Method that takes into account the edge detection has been proposed from Ron Kimmel (Israel) [47]. First, edge indicator is set in the some direction. It is determined that the value of the edge indicator becomes small and that the contribution of the adjacent pixels in that direction is small, when the edge is likely in certain direction. By weighted addition instead of simple addition ratio, the accuracy of the replacement can be improved.

9.3.6 Japanese Technologies

In Japan, methods of applying a means of pixel determination to a complementary color filter array were proposed by Naoki Ozawa et al. and Toshiyuki Akiyama et al. (both Hitachi), who had pioneered the MOS camera [48]-[50]. These ideas were not limited to complementary color filter arrays and could also be applied to a Bayer color filter array.
Also, by changing the pixel replaced by determining the level difference between the pixels, a method for improving image quality and for reducing the spurious signal was proposed by Hiroki Matsuoka et al. (Matsushita Electric Industrial) [51].
Furthermore, the method using vertical and horizontal correlation as described in 9.3.2, was proposed by Akihiro Maenaka et al. (Sanyo) in 2 month lag [52] [53].
This method provided a means of detecting the vertical and horizontal correlation, identifying whether the correlation was strong or weak and then determining the interpolation pixel.

9.3.7 Japanese Demosaicing Technologies

While the above was realized with analog means, research and development of digital demosaicing has been carried out since the 1990s. Method to try to improve the image quality by replacing the pixel was developed by Tetsuya Tetsuya Kuno et al. (Mitsubishi Electric Corporation) [(54)-(57)].

In general, since R G and B components have strong correlation, when the low frequency components of of each pixel are indicated to LPF subscript, followings are obtained,

R_{34}: G_{34} = R_{LPF}: G_{LPF}

Because this equation holds,

$G_{34} = R_{34} \times G_{LPF} / R_{LPF}$

Therefore, the vertical and horizontal correlations of G are followings,

$\triangle G_V$ and $\triangle G_H$,

when $\triangle G_V < \triangle G_H$,

$G_{i,j} = K_{i,j} \times G_{VLPF} / K_{VLPF}$.

Here, K is either R or B.

Similarly,

when $\triangle G_V > \triangle G_H$,

$G_{i,j} = K_{i,j} \times G_{HLPF} / K_{HLPF}$.

Next, replacing the R and B pixels in the following techniques,

$$R_{i,j} = G_{i,j} \times \{R_{i-1,j} + R_{i+1,j}\} / \{G_{i-1,j}+G_{i+1,j}\}$$

$$B_{i,j} = G_{i,j} \times \{B_{i,j-1} + B_{i,j+1}\} / \{G_{i,j-1}+G_{i,j+1}\}$$

A method has been proposed in which a non-linear filter is used instead of the LPF and in which having constraint conditions when using a correlation difference. This reduces the interpolation error and also improves the accuracy of the interpolation [(55)].

Toshiba also proposed a method of generating a virtual pixel to set the position of the reference pixel by analogical reasoning in reference to a color signal that differs from the color of the reference pixel color filter, based on the assumption that all of the RGB components are present in the pixels corresponding to the color filter [(58)-(60)].

Fig. 9.8 (a) shows a method of focusing on the reference pixel G_{22} and generating virtual pixels R_V, B_V.

$$B_v = G_{22} \times 2(B_{21}+ B_{23}) / (G_{11}+G_{13}+G_{31}+G_{33})$$

$$R_v = G_{22} \times 2(R_{12}+ R_{22}) / (G_{11}+G_{13}+G_{31}+G_{33})$$

In the same way, with regard to the reference pixel G_{33}:

$$R_V = G_{33} \times 2(R_{32}+ R_{34}) / (G_{22}+G_{24}+G_{42}+G_{44})$$

$$R_V = G_{33} \times 2(R_{23}+ R_{43}) / (G_{22}+G_{24}+G_{42}+G_{44})$$

Characteristically, these arithmetic expressions obtain the brightness information from the G signal and the color information from the ratio between G and the surrounding R and B pixels, with each calculated from the average pixel values.

In addition to this, university research is also a thriving, such as followings.

The scheme to be restored from the pixel mixture images was proposed by Ikuko Ota and Kiyoharu Aizawa (University of Tokyo) [(61)], a method using Total-Variation regularization was proposed by Takashi Komatsu and Takahiro Saito (Kanagawa University) [(62) (63)] and a method that takes into account color signals having a high spatial frequency, by Taro Sekine et al. (Niigata University) [(64)].

Even in recent times patent proposals are actively applied by Canon, Nikon, Sony and other manufacturers [(65)-(77)].

9.4 Super-Resolution Technology

9.4.1 Increase of Sampling Frequency

The idea of achieving an increased sampling frequency in a video camera by changing the relative position between the image sensor and the optical image with time was proposed by K. A. Hoagland et al. [(78) (79)]. By periodically vibrating the thin glass plate inserted into the optical system and thereby moving the optical image horizontally, this method improves the resolution by effectively doubling the horizontal pixel number [(80)].

The swing CCD, which applies this idea to an actual image sensor was proposed by Nozomi Harada et al. [(81)].

As shown in Fig. 9.12, this method effectively doubles the pixel number by mounting a piezoelectric element under the CCD package to minutely move the array by half a pixel pitch in the horizontal direction.

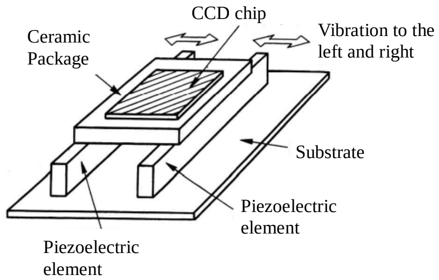


Fig. 9.12 Swing CCD [(81)]

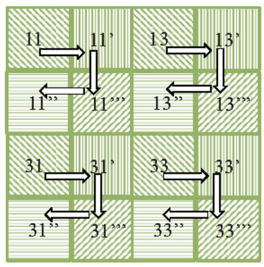


Fig. 9.13 Pixel Increase by Four Imaging

This concept can be extended, as shown in Fig. 9.13. By shooting at the position of each fine movement by repeatedly right, bottom, the left, the four times sampling points are obtained, and can be improved twice vertical and horizontal each resolution. Minutely moving the array repeatedly to the right, bottom and left and capturing an image at each position gives four times as many sampling points, thereby doubling both the vertical and horizontal resolution.

9.4.2 Intra-Frame Super-Resolution Reconstruction

Super-resolution method using intra-frame processing was realized by Takashi Ida, by utilizing the self-congruency property, in which luminance change has the same properties between lines [(82) (83)].

In many cases, the edge portion such as the outline is changed to the same brightness along the edges. In other words, there are a plurality of similar pattern at the edge. This image property is called self-congruency. For example, if we focus on the cheek area in the most important woman's face shown in Fig. 9.14 (a), we see the same intensity change in luminance pattern repeated along the contour. Fig. 9.14 (b) shows a 3-D luminance variation in the contour portion. Here we see that similar changes are numerous.

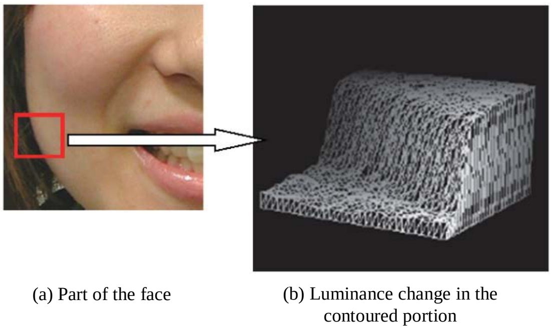


Fig. 9.14 Image Self-Congruency, created with reference to literature (84)

It should be noted here that while the luminance change is the same along the outline area, the position moves little by little horizontally to the right.
This results in a slight change in the pixels above and below the contour sampling position, if sampling is taken at equal intervals from the left of the frame.
Fig. 9.15 provided an illustrated explanation of this. First, the similar pixels are selected, as shown in Fig. 9.15 (a). Next, after adjusting the position, new pixels are interpolated based on the surrounding pixels, as shown in Fig. 9.15 (b). In practice, the number of sampling points on the central pixel line can be increased by calculating from the same relative position on another line, as shown in Fig. 9.16 [85].

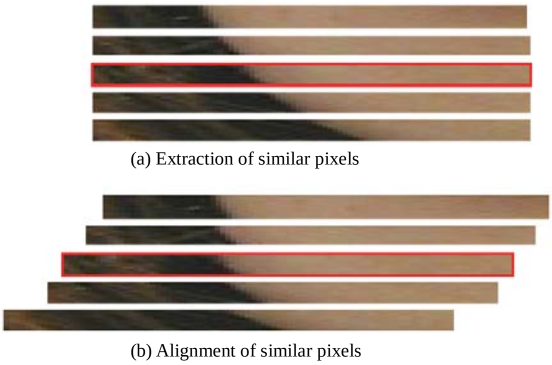


Fig. 9.15 Interpolation using Surrounding Pixels

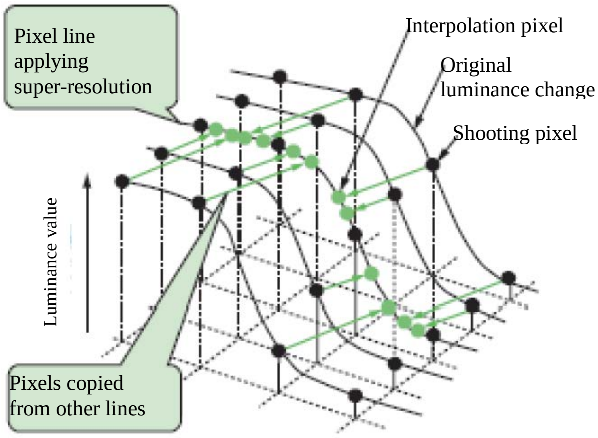


Fig. 9.16 Super-Resolution Method using Intra-Frame Processing [85]

9.4.3 Inter-Frame Super-Resolution Reconstruction
This method refers to the preceding and following frames when increasing the resolution of a moving image frame. There is no change between frames in a static image if the camera is in a fixed position and the subject does not move, however, if the camera or the subject moves, the subject will have different sampling positions between the two frames. If it were possible to rectify this movement and adjust the position of the oblect, it would result in an image with an increased number of sampling points.
Therefore, if movement can be accurately detected, this method can be used to restore high-frequency components and produce a high resolution image.
The intra-frame super-resolution reconstruction method shown in Fig. 9.4.2 has little scope for increasing the resolution of images with no self-congruency. Thus, this method of inter-frame super-resolution reconstruction from multiple images using sub-pixel shift was developed [86] [87]. As shown in Fig. 9.17, the resolution is improved by generating a sub-pixel shift image shifted half a pixel from the pixels of the target frame.

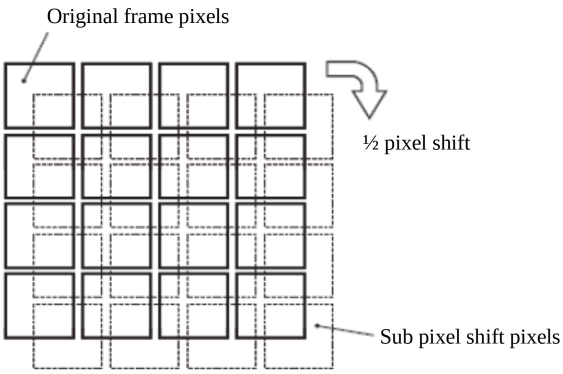


Fig. 9.17 Method of Generating a Sub-Pixel Shift Image [86]

These technologies are used in digital televisions and PCs. For practical use, this requires high-speed processing. Dedicated LSIs have been developed to work with particular equipment. PCs mounted the SpursEngine™ media streaming processor, while digital televisions mounted the MetaBrain™ Premium dedicated LSI imaging engine [86].
These technologies can be expected to have a wide range of applications in imaging devices in the future, from video cameras to digital cameras, mobile phones and smartphones.

9.4.4 Noise Cancel Technologies
It is necessary to minimize the noise in advance in applying super-resolution technology.
In many cases, the conventional noise reduction technology has used frame correlation techniques. However, after these processing, effect of the super-resolution processing is eliminated. Therefore, NL-Means (Non-Local Means) has been noted.

This scheme was proposed by A. Buades et al. (Spain) (88). This method is first calculated as the weight of the similarity between the blocks around the target pixel and the blocks collected in large quantities from the images. Then, taking a weighted average of the central pixel of each block, this technique replaces the target pixel to this value. Based on this method, structure adaptive NL-Means method was developed by Kawada et al. (Toshiba) (89).
An image divided into blocks can be represented by a combination of simple patterns, as shown in Fig. 9.18. Therefore, base pattern robust to noise is learned statistically from natural images. First, it is arranged in the order of frequency of appearance high block of 500 million pieces cut from natural image. 147 pieces from among them have been ordered as shown in Fig. 9.19 (a). A base pattern with a high frequency of appearance represents a local structure that occurs often in a natural image. On the other hand, the base pattern with minimal frequency of appearance can be regarded as a noise component having no correlation to the structure of the image. Then, only the base patterns with a high frequency of appearance are selected, as shown in Fig. 9.19 (b). These patterns are less susceptible to noise. Using these base patterns to replace existing blocks makes it possible to avoid the risk of similar areas being affected by noise. Fig. 9.20 shows a block that has been re-represented using the base patterns given in Fig. 9.19 (c).
There is insufficient space to cover super-resolution technology in detail here. A comparative evaluation of images is given in cited reference (90) and explanations in cited references (91)-(95).

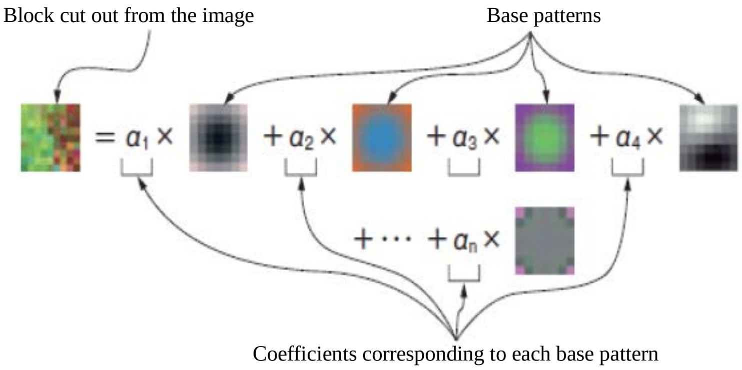
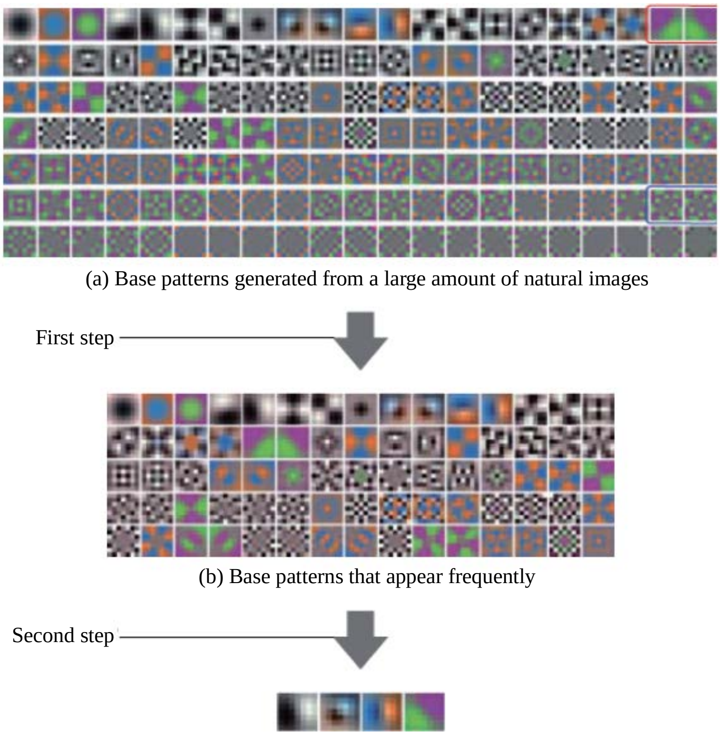


Fig. 9.18 Image Structure using Base Patterns (89)



(a) Base patterns generated from a large amount of natural images

(b) Base patterns that appear frequently

(c) Base patterns correlate highly with their own block

Fig. 9.19 Base Pattern Selection Method [89]

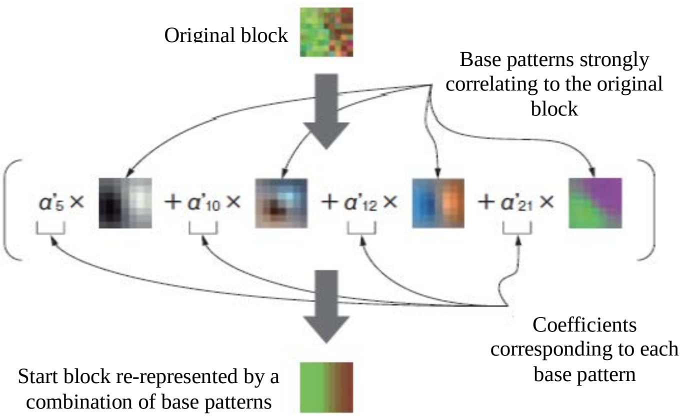


Fig. 9.20 Noise Reduction Method [89]

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10. Video Camera Technology Systematization

10.1 General Technology of Video Cameras

Figure 10.1 illustrates a systematization of video camera technology. Broadly categorized, video camera technology comprises imaging device which is the most important component of the video camera, some optical devices including an imaging lens, optical LPF and the CFA, AFE which corresponds to the pre-processing, digital signal processing of the main part of the video camera and output circuit. The digital signal processing unit consists of the necessary basic circuits processing a video signal, high-performance circuit for obtaining an image without fail and quality enhancement circuit for improving the image quality. A microcomputer is used to control these circuits and the actual processing algorithms are performed by the software.

In addition, a recording equipment and view finder are required. There are optical viewfinders that incorporate part of the optical image and electronic viewfinders with small LCD screens.

10.2 Expansion of Video Camera Technology

Fig. 10.2 shows the expansion of video camera technology. In a large technical flow, electronic cameras (also referred to as electronic still cameras) for recording and reproducing still images were drew attention from the early 1990s. These used a special standard floppy disk for a recording medium at first. However, this did not become widely popular at the time as the resolution was far lower than photographic film and printing paper.

In the late 1990s, technology for digital recording in the semiconductor memory and the number of pixels of the image pickup device has been achieved. Thus technology progress resulted rapid popularization and industry growth overtaking video cameras in terms of production quantity. On the basis of the video camera technologies, further improvement of image quality for still images went under way digital camera.

Mobile phones began to grow in popularity in the late 1990s and camera-equipped mobile phones emerged, incorporating camera miniaturization technology. While this function was initially used instead of the memo function, there was growing demand for taking snapshots. As advances in camera miniaturization and pixel miniaturization technology made it possible for mobile phones to capture images that were on par with compact digital cameras, cameras were built into all mobile phones in Japan. With a growing demand for taking self portrait and couple shots, mobile phones emerged providing both front and rear cameras.

As this function was applied to smartphones and tablets with computer functions, cameras eventually became an integral part of these products.

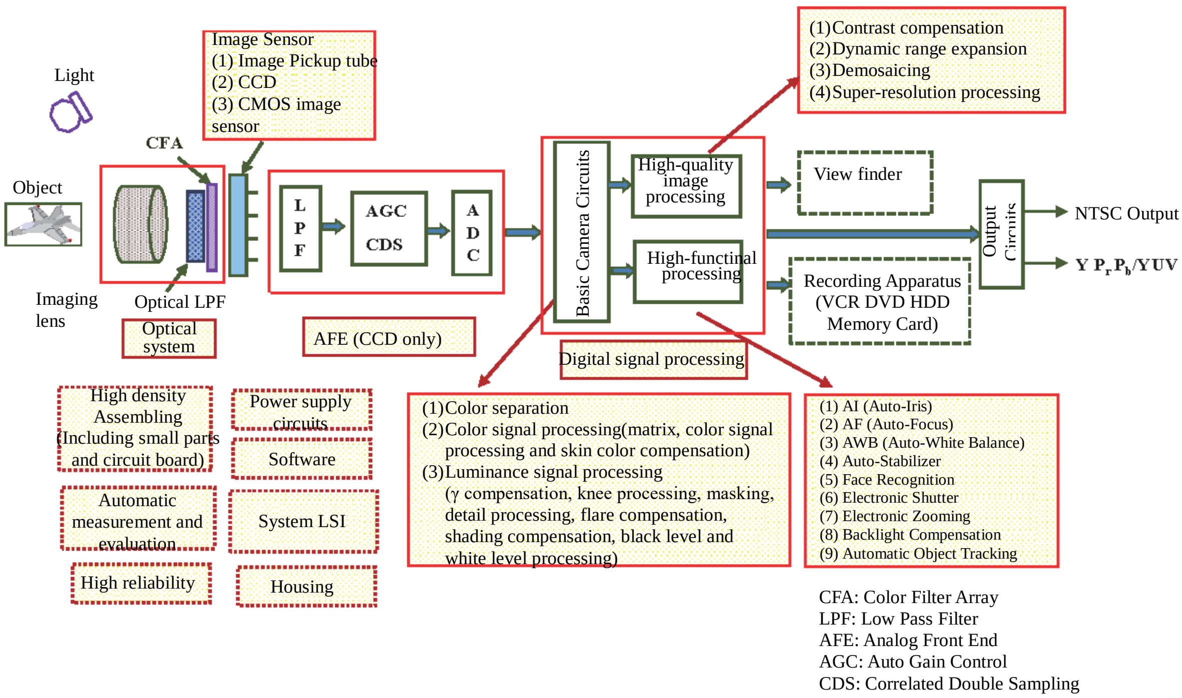


Fig. 10.1 Video Camera Technology Block Diagram

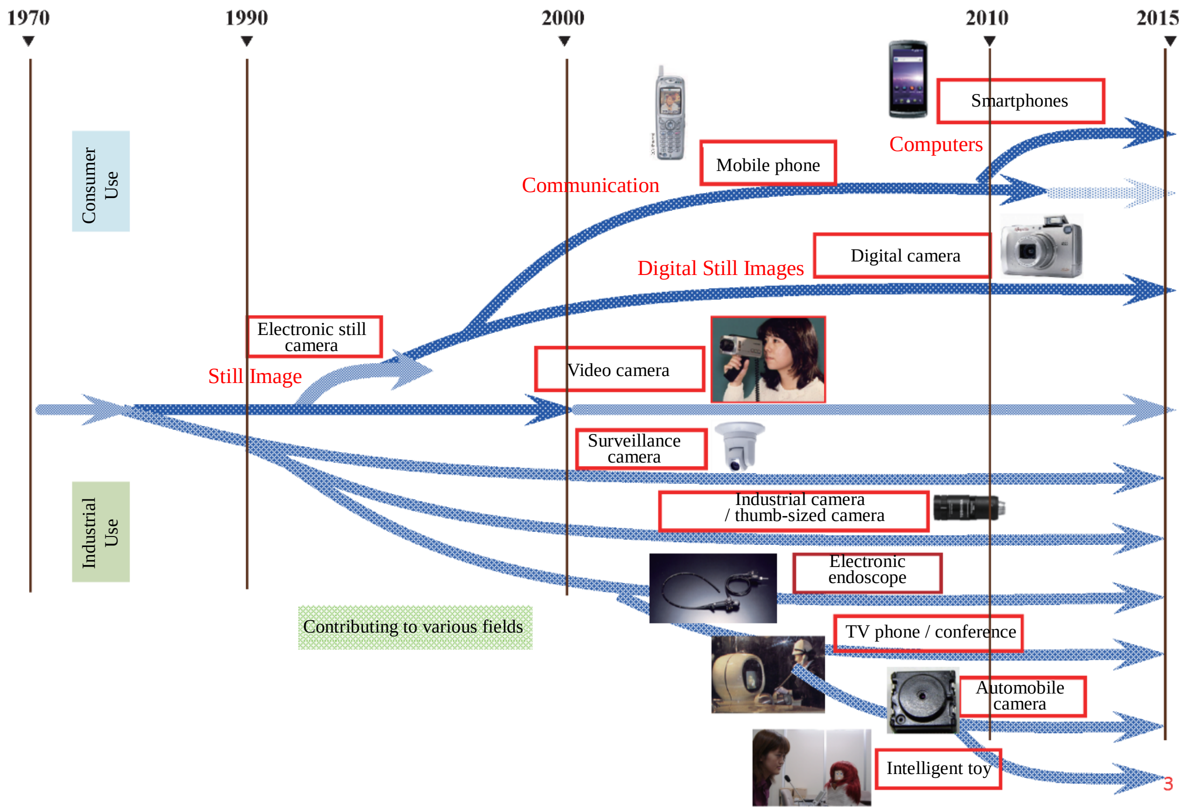


Fig.10.2 Evolution of Video Camera Technology

Meanwhile, in the industrial sector, surveillance cameras were being used for store monitoring and platform safety monitoring. These were also set up on street corners with the idea of providing a crime deterrent effect. This has also been deployment of video camera technology.
While fiberscopes were the main type of endoscopes used in the medical field, these were replaced by electronic endoscopes with a CCD attached to the tip. Since the electronic endoscope can be obtained a clear image, it is highly effective that early disease could be found. It also has the benefit of multiple doctors being able to see the screen at the same time. There is also anecdotal evidence that back pain among doctors has been reduced due to the ease of operation. Use of these cameras has expanded to include rigid endoscopes and laparoscopes, making it possible to go without laparotomy, meaning faster postoperative recovery and a significant alleviation of the burden on the patient.
On the other hand, by mounting a camera on passenger cars has become commonplace, which is also a development of video camera technology. Commercialized products for vehicle-mounted cameras include Parking Assist and Around View for viewing the surrounding environment. Further, vehicle camera developments are expected, such as collision prevention and line-crossing warnings using white line detection.

10.3 Progress of Video Camera Technology

Chronological order video camera technologies are described in Table 10.1, and the progress of technology are summarized. This table was compiled with reference to the annual report published in the July issue of ITE Journal every second year, as well as cited references (1) and (2). Technical items are shown on the vertical axis, while the country of origin of the technology is indicated by the line thickness for each item. World's first and the Japan's first Video cameras are listed in Table 10.2.
The evidence for these selections is summarized in Table 10.3. Table 10.4 lists potential technology heritage candidates based on the research to date.

10.4 Role and Contribution of Society Activity

Contributions from the Association's background was supposed to produce one after another of these technological achievements. In particular, it can be mentioned that through the Institute of Television Engineers in Japan (ITE current), researchers and engineers worked together for many years, taking steps towards a common goal.
A large number of human resources came together in the camera field in the late 1970s and 1980s, when rapid progress was being made in camera technology. In addition, good leaders had been enrolled in the institution and each manufacturer. Despite the small size of the video camera, it contained an adept combination of advanced technology. Academic conferences and journals provided the opportunity to present and publish findings on these new technologies. Idea exchange is performed for the advancement of technology in these fields, young engineers are empathetic guidance, and were being nurturing. Then, cooperation beyond the boundaries of the manufacturers were being built. These gave a stimulus to the young engineers of each manufacturer and were carried out a brilliant achievement to be proud of in the world.
Those who are contributing to these are Messrs below; Teruo Ninomiya (NHK), Yuji Kiuchi (Toshiba) and Takao

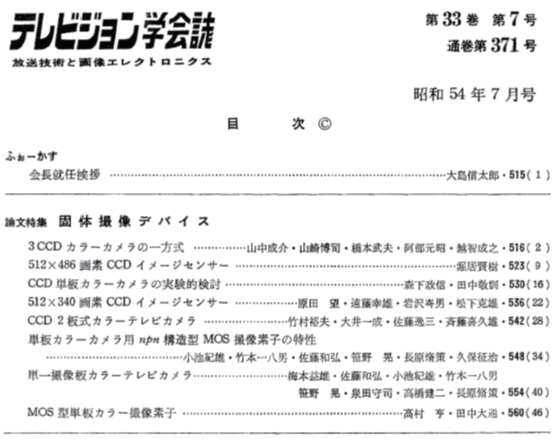
Ando (Shizuoka University) who both have lead as chief of the Electronic Devices Research Committee at the time, Shin Hasegawa (University of Electro-Communications) and Shusaku Nagahara (Hitachi) who have been chief of the System and Circuits Study Group, Takanori Okoshi (University of Tokyo), Mikio Ashikawa (Hitachi) and Shigeo Tsuji (Toshiba) who have been taught in the editorial committee.

As shown in Fig. 10.3 and Fig. 10.4, some of these activities are described in round-table discussion, which was published in the Journal, etc. [(3) - (5)].

Joint Study Group of the circuit system and an electronic device to be held in March every year in particular has been attracting attention as a study group to report the results of one year. In many cases, conference room became overcrowded with researchers and engineers of the imaging device and the video camera. Then, hastily, large conference hall that can accommodate many participants was prepared. From time to time, the Editorial Board of the Institute of Television Engineers would plan the special issues of imaging. These activities also spread overseas, with manufacturers focusing on technical committees in March. Philips engineers are said to have reserved the Prince Hotel near the venue and immediately started translating the Japanese-language research papers for their research [(6)].

The first special issue of the Journal of the Institute of Television Engineers was published in July 1979, as shown in Fig. 10.3. The idea surfaced that it should have images printed in color, perhaps because it was about color imaging devices. This idea came to pass and it was printed in color, which was a rarity at the time. Teruo Ninomiya, editor-in-chief at the time said followings;

"This special issue was sold out as soon as good reputation. Surprisingly, when I met the foreign people who are associated with the image sensor, everyone bought and had it. Prominent researchers, such as Dr. Wymer (RCA), Mr. Giyosu (Thomson CSF) also have it, and interest of the book was also higher in foreign countries [(7)] "



テレビジョン学会誌
放送技術と画像エレクトロニクス

第33巻 第7号
通巻第371号

昭和54年7月号

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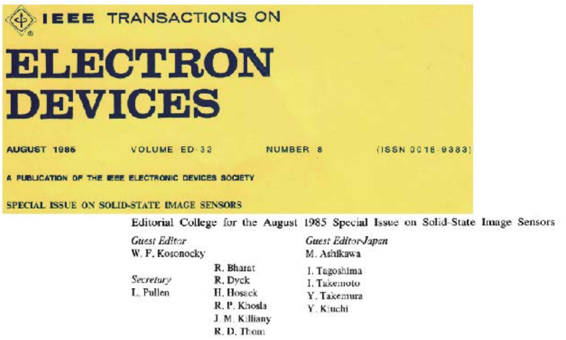
Fig.10.3 Part of the ITE Journal Special Issue Contents [(8)]

The goal was to export the video camera to the whole world. Therefore, the latest technological achievements of imaging devices were presented to the IEEE ISSCC and IEDM, while video cameras achievements were presented to the ICCE. Through these activities, the world's highest technology level from Japan was appealed to the foreign countries. The IEEE Image Sensor Workshop, held once every two years, has also been active in recent years.

IEEE: Institute of Electrical and Electronics Engineers
IEDM: International Electron Devices Meeting
ISSCC: International Solid-State Circuits Conference
ICCE: International Consumer Electronics Conference

Many papers were also published in the following journals:
IEEE Transactions on Electron Devices
Journal of the Solid-State Circuits
IEEE Transactions on Consumer Electronics

The August 1985 edition of IEEE Trans. Electron Devices included a Special Issue on Solid-State Image Sensors was edited by at August 1985. As shown in Fig.10.4, Mikio Ashikawa (Hitachi) was selected as a guest editor, together with industry leader Walter F. Kosonocky. Five Japanese engineers were included among the 13 editorial members and carried out a paper peer review [(9)].



IEEE TRANSACTIONS ON
ELECTRON DEVICES
AUGUST 1985 VOLUME ED-32 NUMBER 8 (ISSN 0018-9383)
A PUBLICATION OF THE IEEE ELECTRONIC DEVICES SOCIETY
SPECIAL ISSUE ON SOLID-STATE IMAGE SENSORS

Editorial College for the August 1985 Special Issue on Solid-State Image Sensors

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W. F. Kosonocky

Guest Editor-Japan
M. Ashikawa

Secretary
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R. Bharat
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H. Hosack
R. P. Khosla
J. M. Killiany
R. D. Thom

I. Tagoshima
I. Takemoto
Y. Takemura
Y. Kiuchi

Fig.10.4 Part of the IEEE Trans. ED [(9)]

For this special issue, 17 papers from Japan, 15 the United States and 5 Europe were adopted in this special issue. It was said that the image sensor and video camera journals could no longer be maintained value of the Journal without Japanese technical papers.

Meanwhile, although the August 1983 issue of IEEE Trans. Consumer Electronics was not solely related to video cameras, the 40 papers published included 21 from Japan, 8 from the United States, 10 from Europe and 1 from India [(10)].

These activities were highly appreciated from all over the world, and Japanese technology in these fields became the unwavering in the world.

Table 10.1 Schematic Diagram of Video Camera Technology

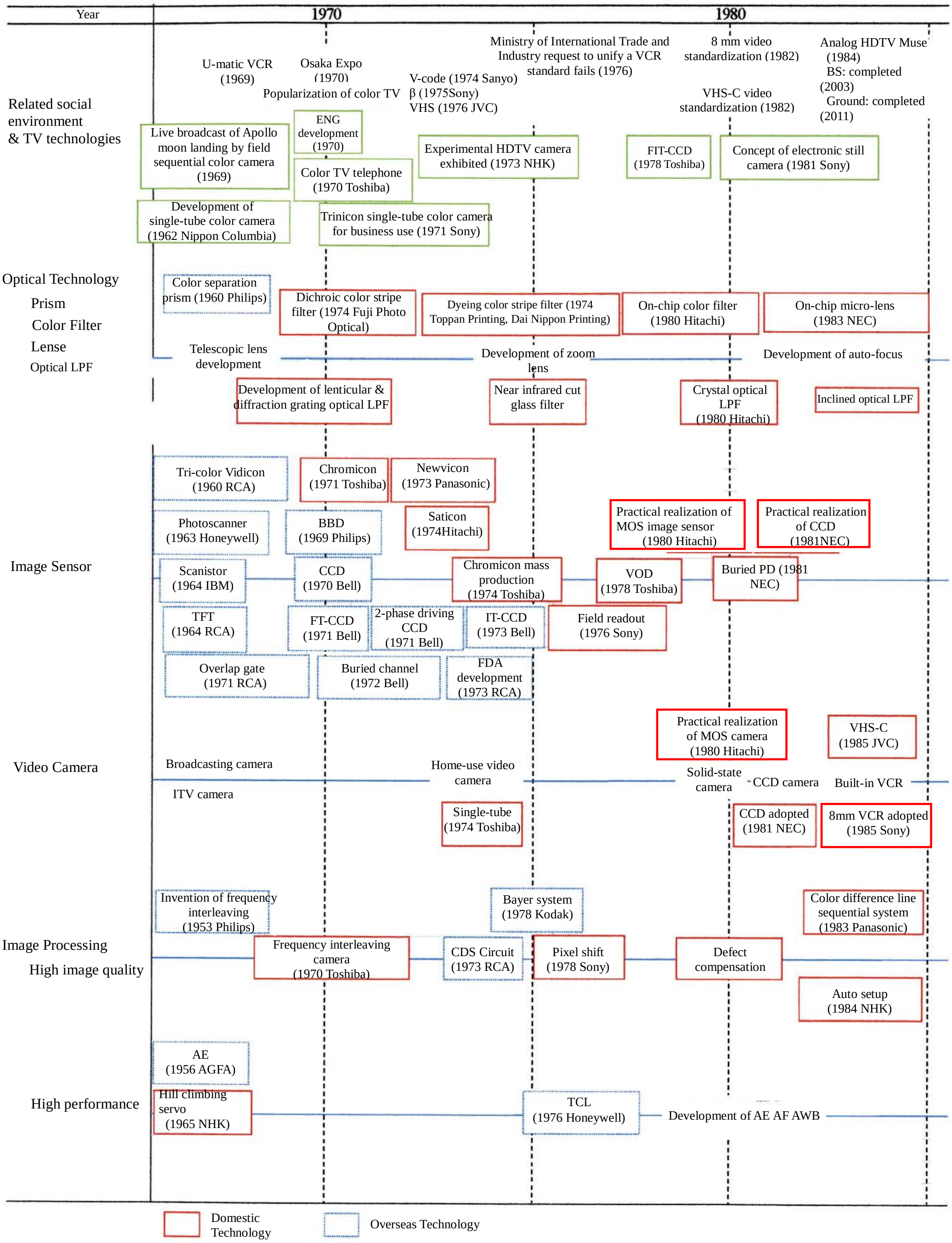

Table 10.1 refers to the following literature and sources.

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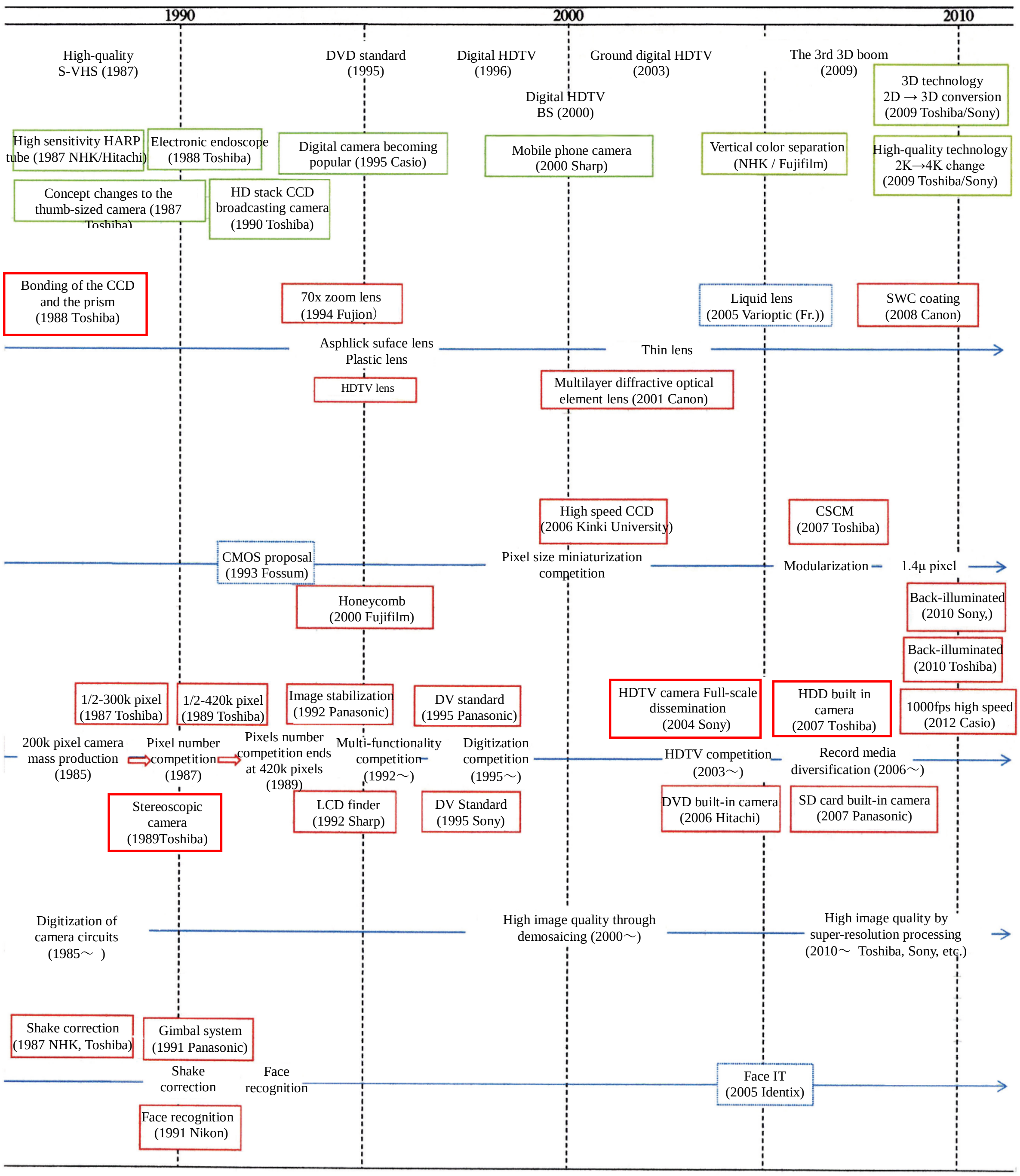

(5) Nobukazu Teranishi: 10 Findings that Undergirded 20th Century Developments in Solid-State Imaging Technology, ITE Journal, Vol. 54, No. 2, pp. 141-147, Feb. 2000.
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Table 10.2 The World’s First and Japan’s First Video Camera

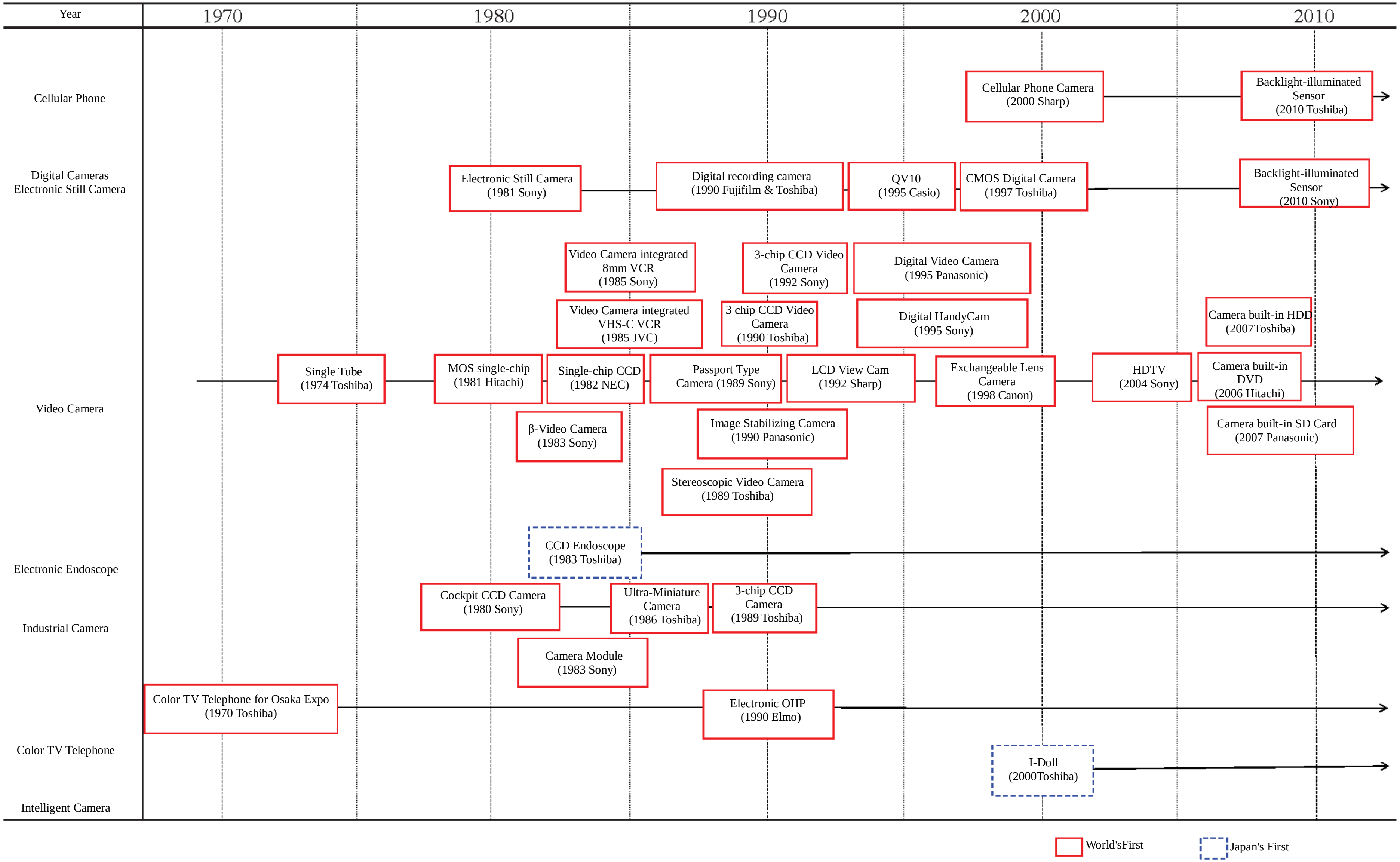

Table 10.3 Evidence for World-Firsts and Japan-Firsts

[Video Cameras]

Title	Year	Maker	Type	Reason
Video Camera	1974	Toshiba	IK-12	The world's first home-use video camera built-in color stripe filter Vidicon. Roots of video camera.
MOS Single-Chip	1981	Hitachi	VK-C1000	The world's first home-use video camera using MOS image sensor
CCD Single-Chip	1982	NEC	TC-100	The world's first home-use video camera using CCD
Beta VCR integrated Video Camera	1983	Sony	BMC-100	The world's first video camera integrated recording apparatus
VHS-C VCR integrated Video Camera	1985	JVC	GR-C1	The world's first video camera integrated VHS-C VCR
8mm VCR integrated Video Camera	1985	Sony	CCD-V8	The world's first video camera integrated 8mm tape VCR
Passport Size Video Camera	1989	Sony	CCD-TR55	The world's first small-scale video camera miniaturized to passport size. Spread in earnest begins.
Stereoscopic Video Camera	1989	Toshiba	SK3D7	The world's first 3D video camera using compound eyes. 500 units launched in the U.S.
Shake Correction Video Camera	1990	Panasonic	NV-S1	The world's first video camera using the hand-shake correction
3-chip CCD Video Camera	1990	Toshiba	BCC-100	The world's first 3-chip video camera. The world's first automatic machine combining precise between CCD and prism
3 chip CCD Video Camera	1992	Sony	CCD-VX1	Flagship model for the 3-chip CCD home-use video camera
LCD ViewCam	1992	Sharp	VL-HL1	The world's first video camera with LCD finder.
DigiCam	1995	Panasonic	NV-DJ1	The world's first digital video camera. DV recording system
Digital Handycam	1995	Sony	DCR-VX1000	The world's first digital video camera. DV recording system
Lens Exchange Capable System	1998	Canon	XL-1	The world's first video camera capable exchange lens
Authentic HDTV Camera	2004	Sony	HDR-FX1	True HDTV video camera with 1080 TV line resolution
Camera built-in DVD	2006	Hitachi	DZ-GK3300	The world's first HDTV video camera with a DVD recording medium.
Camera built-in HDD	2007	Toshiba	GSC-A100F	The world's first HDTV video camera with a HDD recording medium.
Camera built-in SD card	2007	Panasonic	HDC-SD1	The world's first HDTV video camera with an SD card recording medium

[Video camera related]

Color TV Telephone	1970	Toshiba		The world's first color TV telephone demonstration exhibited at the Osaka World Expo between the Expo Telecommunications Pavilion and the Kasumigaseki Building
Electronic Still Camera	1981	Sony		The world’s first prototype of today’s digital cameras. A striking prototype with the catchphrase, Goodbye film!
Ultra-Miniature Camera	1986	Toshiba	IKM10B	Ultra-compact camera having a 16.5mm diameter camera head. This camera revolutionized the idea of the box-type camera.
3-chip CCD Surveillance Camera	1988	Toshiba	IKT-30C	The world's first three-chip compact camera. Development of highly accurate automated bonding between the CCD and prism
Digital Recording Camera	1990	Toshiba & Fuji film	DS-X	The world's first digital camera with a semiconductor memory as a recording medium. Forerunner of the current digital camera
Visual Presenter	1990	Elmo	EV101	Electronic OHP (overhead projector).The world's first electronic OHP using CCD camera
Authentic Digital Camera	1995	Casio Computer	QV10	Flagship that led to full-scale spread start
CMOS Digital Camera	1997	Toshiba		The world's first digital camera using a CMOS image sensor
Cellular Phone Camera	2000	Sharp	J-SH04	The world's first mobile phone camera released by J-Phone.
Back-Illuminated Sensor for Camera	2010	Sony		The world's first 16.41 million pixel back-illuminated CMOS image sensor
Back-illuminated Sensor for cellular phone	2010	Toshiba		The world's first 14.60 million pixel back-illuminated CMOS image sensor for mobile phone
CMOS Image Sensor having largest number of pixels	2010	Canon		The world's largest 120 million pixel CMOS-APS image sensor.

Table 10.4 Important Video Camera and Video Camera related Technologies

(a) Video Camera

No.	Name	Situation	Location	Manufacturer	Year	Selection Reason
1	Solid-State Video Camera VK-C1000	Storage	Ibaraki Prefectural Museum of History Mito	Hitachi	1981	The world's first solid-state video camera using MOS Image Sensor
2	Single-Tube Video Camera IK-12	Exhibit	Toshiba Science Museum Kawasaki	Toshiba	1974	The world's first home-use video camera using color stripe filter built-in Vidicon. Roots of the video camera
3	CCD Video Camera TC-100	Investigation	-	NEC	1982	The world's first CCD video camera
4	Passport Size Video Camera CCD-TR55	Exhibit	Sony History Museum Tokyo	Sony	1989	The world's first passport size compact video camera Full-scale dissemination for home use began by this camera
5	Video Camera Brenby NV-S1	Storage	Panasonic AVC Okayama Plant Okayama	Panasonic	1990	The world's frst hand-shake correction video camera
6	Stereoscopic Video Camera SK3D7	Exhibit	Toshiba Science Museum Kawasaki	Toshiba	1989	The world's first stereoscopic video camera Roots of stereoscopic camera
7	LCD ViewCam VL-HL1	Exhibit	Sharp Museum Tenri	Sharp	1992	The world's first LCD video camera Previously using small CRT
8	VCR integrated Video Camera BMC-100	Exhibit	Sony History Museum Tokyo	Sony	1983	The world's first video camera integrated recording medium Previously connected by a cable to a separate recording device
9	8mm Video Camera CCD-V8	Exhibit	Sony History Museum Tokyo	Sony	1985	The first video camera using the 8mm cassette
9	VHS-C Video Camera GR-C1	Storage	JVC VHS Memorial Museum Yokosuka	JVC	1985	The first video camera using the VHS-C cassette
11	3-CCD Video Camera BCC-100	Under investigation		Toshiba	1990	The first 3-chip CCD video camera using the world's first automatic machine combining precise between CCD and prism
11	3-CCD Video Camera CCD-VX1	Storage	Sony History Museum Tokyo	Sony	1992	Flagship model of the professional video cameras
13	Digital Video Camera NV-DJ1	Storage	Panasonic AVC Okayama Plant Okayama	Panasonic	1995	The world's first digital video camera using DV recording format
13	Digital Video Camera DCR-VX1000	Storage	Sony History Museum Tokyo	Sony	1995	The world's first digital video camera using DV recording format

(b) Video Camera related

No.	Name	Situation	Location	Manufacturer	Year	Selection Reason
1	Cellular Phone Camera J-SH04	Storage	Sharp Museum Tenri	Sharp	2000	The world's first mobile phone camera released by J-Phone. Roots of mobile phone camera
2	Ultra-Miniature Camera IKM10B	Storage	Toshiba Science Museum Kawasaki	Toshiba	1986	Ultra-compact camera having a 16.5mm diameter camera head Revolutionized the size of the video camera
3	Color TV Telephone —	Investigation		Toshiba	1970	The world's first demonstration exhibited between telecommunications pavilion at the Expo and the Kasumigaseki Building
4	Electronic OHP EV101	Investigation		Elmo	1990	The world's first electronic OHP with a CCD camera Electronic OHP (overhead projector)
5	Cockpit Camera XC-1	Storage	Sony History Museum Tokyo	Sony	1980	CCD implemented for the first time in the world Installed in the All Nippon Airways jumbo jet
6	Cockpit Camera —	Investigation		Panasonic		Installed in a Japan Airways jumbo jet

10.5 Future Prospects of Video Camera Technology

Research and development in the video camera technology have been investigated. Future prospects of video camera technology will be discussed from here.

10.5.1 Desire to Moving Image

Camera technology has progressed with time, with video camera technology at its core, as shown in Fig. 10.2. It has developed with changes in form, including digital cameras, mobile phones, smartphones and tablet devices. Although it is a little more complicated than still images, our desire for shooting and storing moving images is not going to abate.

10.5.2 High Image Quality

In digital television, increasing of pixel numbers is progressing from 2K x 1K, the so-called 2 million pixel HDTV, to 4K x 2K, four times. However, rather than increasing the number of pixels by force, the image processing technology will become common to convert the image from 2K to 4K. This has been the case throughout the history of increases in pixel number, as simply increasing the number of pixels the side effects of sensitivity and dynamic range reduction may occur. As mentioned in Chapter 9, there are significant advances in super-resolution and demosaicing technology. If these technologies of the Japanese image making were applied, high-definition novel video camera could be born.

10.5.3 3D Technology

We also have a strong appetite for 3D displays. Unfortunately, the 3D digital television boom of two years ago proved to be temporary, because there had no essential change in the technology in the past 25 years. compatibility with 2D television and the nuisance of wearing 3D glasses have to be resolved.

Again, 2D→3D conversion technology is attracting attention. Even if a broadcaster transmits in 2D, it could be possible to convert the signal to 3D at the receiver. If compatibility with 2D could be maintained, we could expect to see the spread of 3D television gain momentum. Glasses-less 3D TV has also come to the stage of practical use in the art. If this were to proceed, 3D video camera is a necessity.

Advances in semiconductor technology have made it possible to implement previously-problematic advanced image processing methods, thanks to increases in speed and capacity. Future progress in the video camera is full of unlimited possibilities. I believe this is the direction in which Japanese technology is headed.

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11. Conclusion

This report has provided video camera technologies systematization, describing specific technology of video cameras. The achievements in video camera technology are the results of tireless imagination by researchers and engineers and their efforts and commitment to research and development. In particular, it was noteworthy that key technologies in it built up by Japanese researchers and engineers. Video cameras have grown into a major industry and have been widely favored to people all over the world. These results are uniquely meaningful and are a pleasure indeed for researchers and engineers who have been involved in the development.
It has been very grateful for me to have been able to participate its activities and to have been able to write this report.
The technology made up the video camera covers a broad range of fields. In addition to the technologies described in this report, these also includes such technologies, as following; viewfinders, LSI for cameras, microcomputer technology to control video camera functions, related software technology, casings and other structural technology, high-density implementations to mount components onto circuit boards and evaluation and high reliability technology at the core of mass production. Since these technologies are common to many consumer electronics products, they had to be omitted here due to space constraints. I hope that these technologies may be covered from a different angle in other research.
It must not be forgotten that these technologies were created by researchers and engineers working together towards common goals through the society activities. A large number of human resources came together in the video camera field in the late 1970s and 1980s, when video camera technologies progressed rapidly. Video cameras were already capable of capturing acceptable fine images using image pickup tubes and it was not easy to make up a high-performance video camera using the new CCD imaging device. To raise the technical level, engineers have played a technical improvement by presenting new ideas to others outside the company and by overlaying discussion with friends. Journal and Research Committee of the Institute of Television Engineers of Japan (now the Institute of Image Information and Television Engineers) provided a forum for presentation and an exchange of ideas ensued, aimed at the advancement of the technology. Empathetic guidance to young engineers and a network of collaboration was built up by technology veterans of each manufacturer beyond company boundaries. When electronic devices study group or method and circuit study group were held, participants had been overflowed at any time. After the meetings, participants fed out to the tavern and continued their passionate discussions until late.
Since a limited space, it has not been possible to provide technical details in this report. Accordingly, the cited literatures described in detail, including all authors listed as possible for ease of searching.
I would like to effectively utilize readers these resources.

Acknowledgments
The author received the cooperation of many people when describing this report and expresses sincere thanks to the following people in particular, who provided interviews, valuable comments and resources.

Toru Mochizuki (ITE Secretary-General)
Keiko Okimune (ITE Editorial Responsible Officer)
Tomoko Kanno (Ministry of Economy, Trade and Industry Patent Office)
Nobukazu Teranishi (Panasonic Corporation, Image Sensor Technology Planning Officer)
Daisaku Abura (Yucaly Optical Laboratory
Masao Suzuki (Canon Inc.)
Kiyoshige Shibasaki (Nikon Corporation)
Fumio Nagumo (formerly of Sony Corporation)
Kazuhiro Sato (formerly of Hitachi Ltd.)
Takao Kuroda (formerly of Panasonic Corporation)
Hirokazu Sekime (formerly of Toshiba Corporation)
TetsuoYamada (Tokyo Polytechnic University)
Kazushige Oi (Fuji Xerox Co., Ltd.)
Yasuyuki Asada (formerly of Toshiba Corporation)
Mitsuru Kawasaki (formerly of NEC Corporation)

The author also expresses sincere thanks to the following people, who kindly provided the materials on which Table 6.5 is based, including examining video cameras models.
Toshinobu Haruki (formerly of Sanyo Electric Co., Ltd.)
Hideki Toyoda (formerly of Sanyo Electric Co., Ltd.)
Yasushi Watanabe (formerly of Sharp Corporation)
Yasuo Kusano (formerly of Sharp Corporation)
Ikumi Minema (formerly of Victor Company of Japan, Ltd.)
Hiromichi Tanaka (formerly of Panasonic Corporation)
Tadashi Nagai (Panasonic Corporation)
Toshiya Fujii (Panasonic Corporation)
Sony Corporation Information Center

The author further wishes to express gratitude to the following people, who assisted in locating items.
Ibaraki Prefectural Museum of History: Ikuo Ikeda (Assistant Director), Tadao Ohtsu (Curator Director of Materials), Masaki Osato and Yoko Noguchi
Toshiba Science Museum: Boyon Kim
Sharp Museum: Yuriko Fujiwara
Panasonic Corporation, AVC Network Company: Isamu Miyai
JVC Kenwood Corporation, VHS Museum: Hisao Hino, Hiroyuki Hiraoka, Masaharu Toyono and Kazunori Tanabe

Glossary of Acronyms

ACPI method: Adaptive Color Plane Interpolation, a demosaicing method
ADC: Analog to Digital Converter
AE: Auto Exposure, also called AI: Auto Iris
AF: Auto Focus
AFE: Analog Front End, CCD pre-processing circuit
AGC: Automatic Gain Control
AMI: Amplified MOS Intelligent Imager
APD: Avalanche Photodiode Device
AS: Auto Stabilization
AWB: Auto White Balance
BASIS: Base Stored Image Sensor
Bayer method: Primary-color filter array invented by Bayer
BBD: Bucket Brigade Device
CCD: Charge Coupled Device
CDS: Correlated Double Sampling Circuits
CFA: Color Filter Array
CHBI: Constant Hue Based Interpolation, a demosaicing method
CID: Charge Injection Device
CTD: Charge Transfer Device
CMD: Charge Modulation Device
CMOS image sensor: Complementary Metal Oxide Semiconductor image sensor
CPD: Charge Priming Device
DSC: Digital Still Camera
CSD: Charge Sweep Device
DSP: Digital Signal Processor
DV system: Digital Video system, a digital VCR format
DVD: Digital Versatile Disc, Digital Video Disc
EFP camera: Electronic Field Production Camera
ENG camera: Electronic News Gathering Camera
FD: Floating Diffusion
FGA: Floating Gate Amplifier
FF-CCD: Full Frame CCD
FIT-CCD: Frame Interline Transfer CCD
FT-CCD: Frame Transfer CCD
HCCD: Horizontal Transfer CCD
HDD: Hard Disc Drive
HDTV: High Definition Television
I-Doll: Intelligent Doll
IEEE: The Institute of Electrical and Electronics Engineers, the world’s largest electrical engineering association with 300,000 members
IT-CCD: Interline Transfer CCD, also called IL-CCD
ITO: Indium Tin Oxide Nesa coating
LPF: Low Pass Filter
LSI: Large Scale Integrated Circuits
NL-means: Non-Local Means, an image processing method
PD: Photo Diode
PbO: Lead oxide
Sb_2S_3: Antimony trisulfide
SD: Secure Digital Memory
SIT: Static Induction Transistor
S/N: Signal to Noise Ratio
TCL: Through the Camera Lens, an automatic focus method
TSL: Transversal Signal Line
VCCD: Vertical Transfer CCD
VHS: Video Home System
VOD structure: Vertical Overflow Drain structure
VCR: Video Cassette Recorder